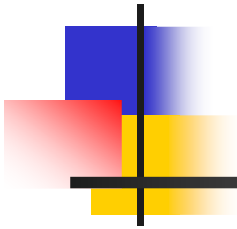


WBIA Industry Days Recovery Boiler Presentation Appleton, WI.



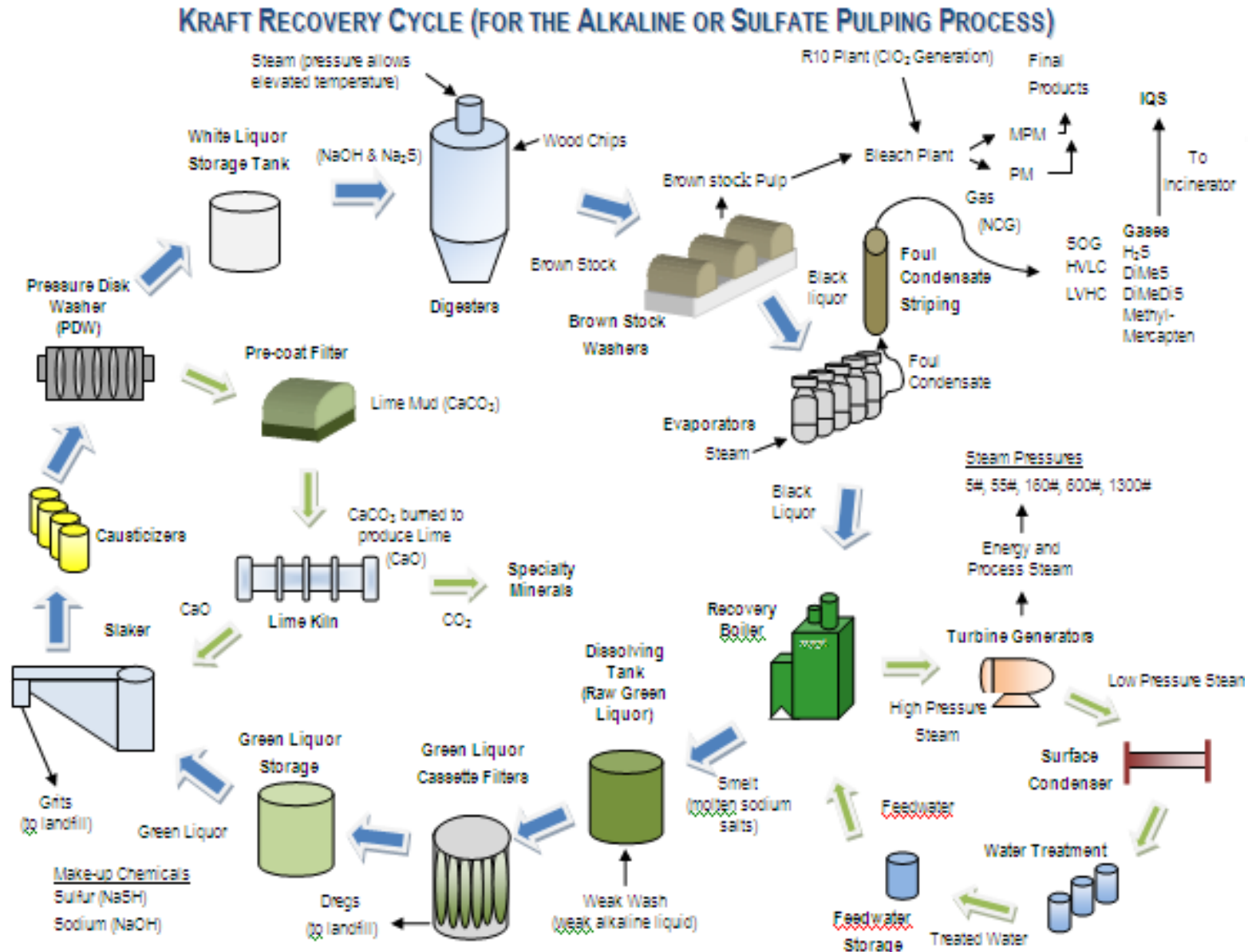
Presented by Bob DeCaigny

April 24, 2013



Objectives

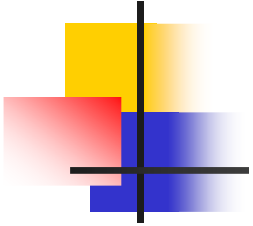
1. Kraft recovery cycle overview
2. Recovery boiler explosion history (25 events in 28 years)
3. What Operators can do to reduce risk of a smelt/water reaction
 - a. Pressure part leak detection
 - b. Follow protocols and procedures
 - c. BLRBAC and AF&PA recommendations
4. Design improvements
5. Where Inspectors can look





Review of RB Explosions

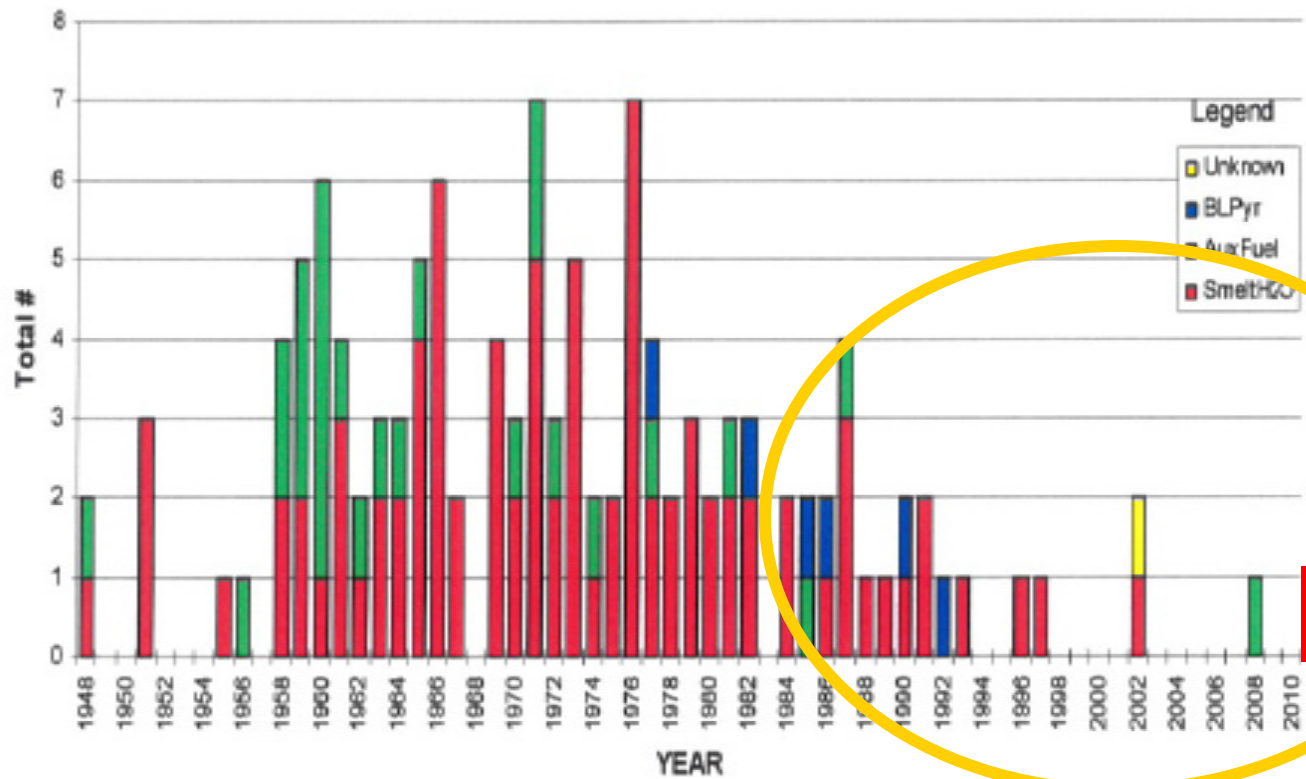
- 25 RB explosions with damage in past 28 years in North America; $\approx 1/\text{year}$ from 1984 to 2012
- The majority are caused by pressure part leaks or mechanical failures. About half involve the inability to recognize the leak followed by a hot restart.
- If ≈ 100 RB incidents/year (estimated that only 70% of all incidents are reported), then **99% of RB incidents *do not* result in an explosion** (due to leak location, conditions, proper operator action or luck)
- 1984 there were ≈ 350 RB's in service; now less than 200:
 - New large RB's replace several smaller units
 - Mills shut down, companies merge & some capacity moves overseas



BLRBAC RB Explosion Data

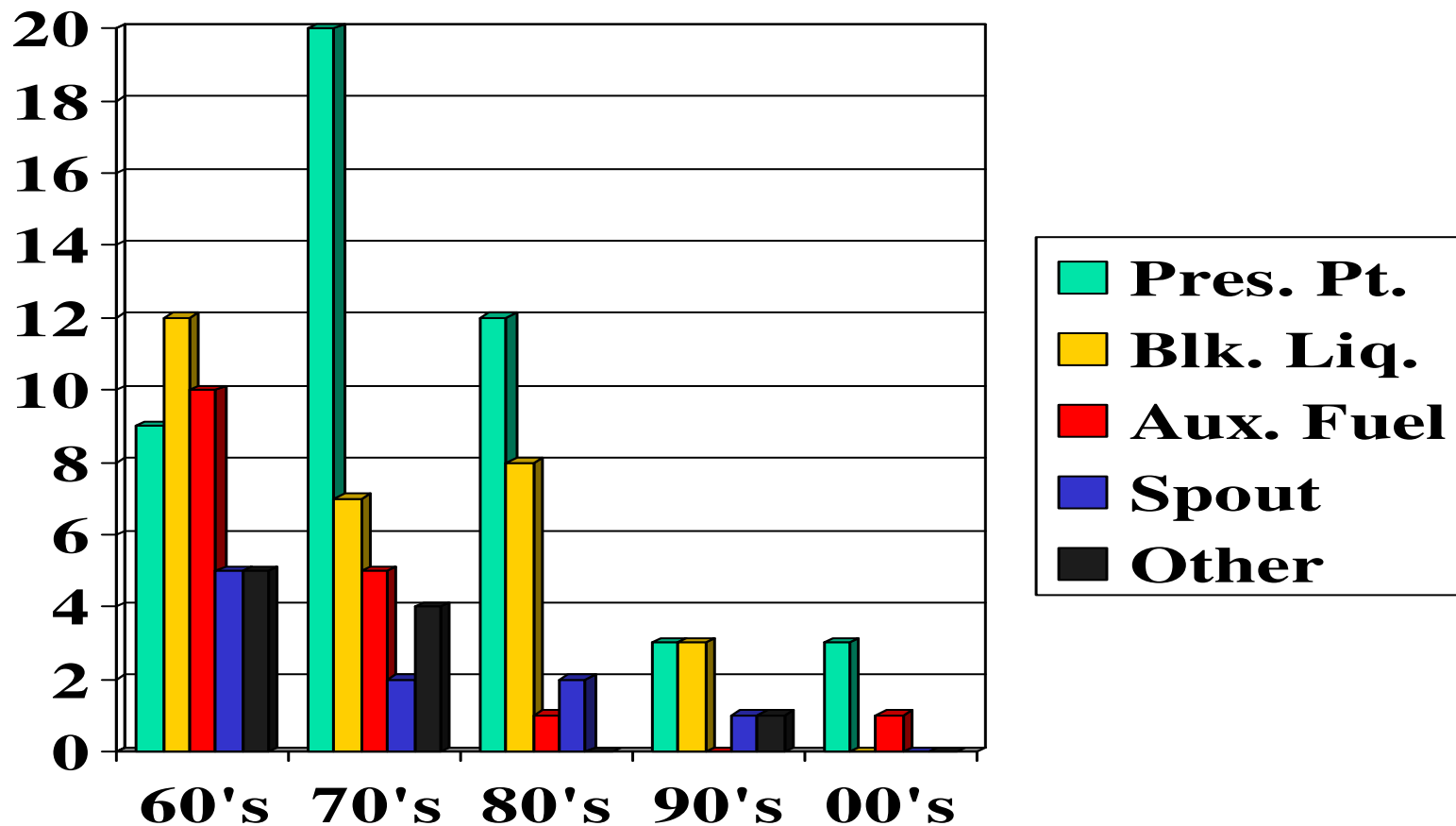
KRAFT RECOVERY BOILER EXPLOSIONS

North America Pulp and Paper Industry



RB Explosion Sources

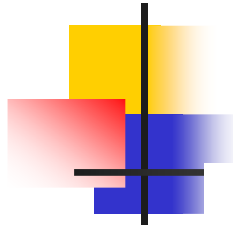
(50 years--USA & Canada)



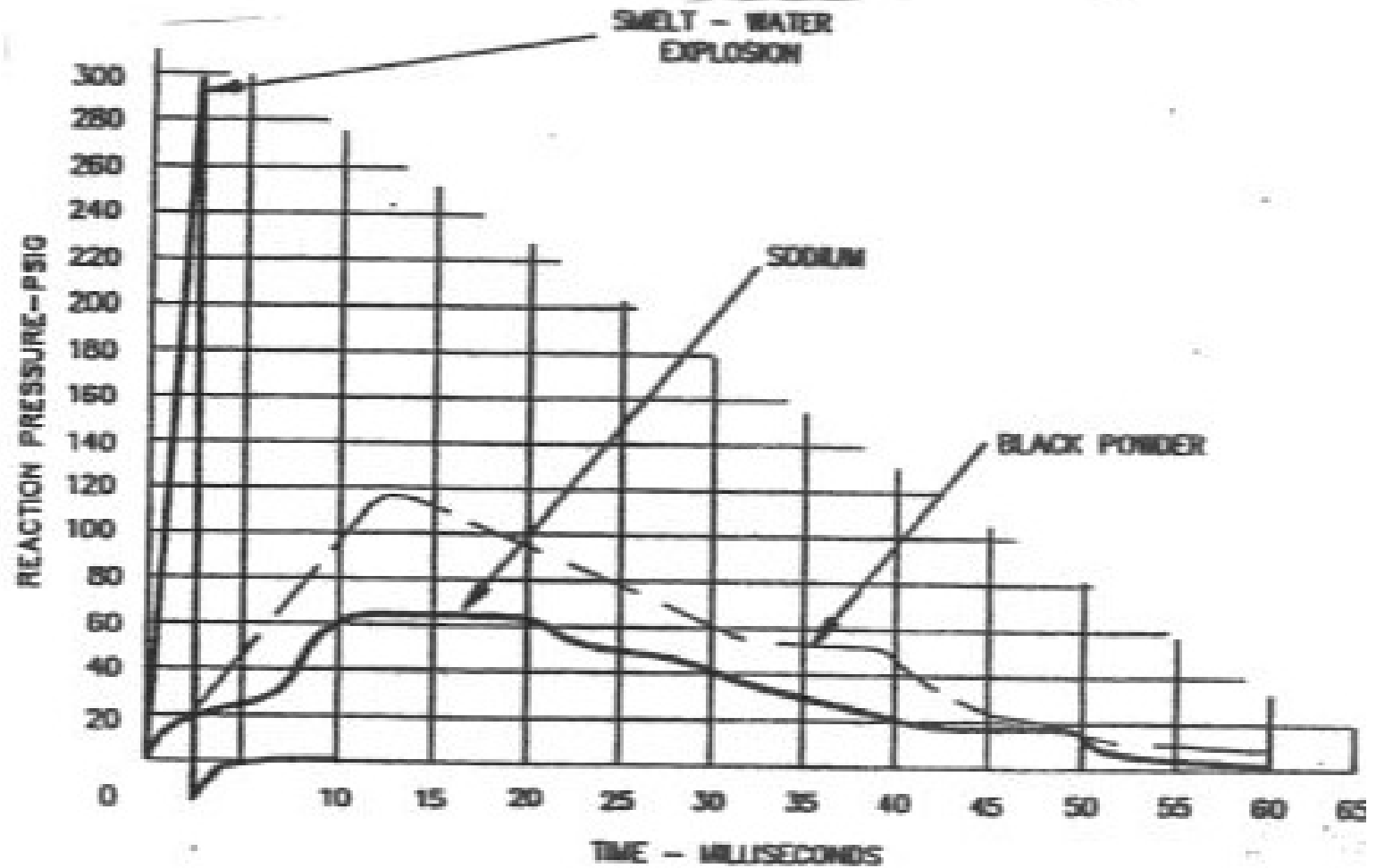


Smelt-Water Reaction

- Smelt bed temperature is $>1500^{\circ}\text{F}$
- Water that contacts the bed expands very rapidly as it boils, increasing ≈ 1500 times in volume, creating a very large shock wave
- Steps in a RB that lead to a S-W reaction (**explosion**):
 - Water comes in contact with smelt
 - Some event triggers mixing of some of the smelt and water
 - Water that intimately mixes with the smelt vaporizes rapidly, resulting in a shock wave that intimately mixes additional smelt & water
 - The additional smelt-water mixing leads to a much larger shock wave (**explosion**)



Smelt-Water Reaction





Review of RB Explosions

- When reviewing each incident, ask;
 - What was done right?
 - What went wrong?
 - How are the RBs you are involved with protected from this type of incident occurring?
 - Do any RB procedures, practices, configurations or designs need to be modified to prevent a similar incident?



Recent RB Explosions (S-W)

1. Unit brought on line, spout cooling water valve closed, spout failed resulting in moderate damage and two weeks of downtime. Event led to BLRBAC recommendation to eliminate valves on spout cooling discharge and later for logic to prove smelt spout cooling flows OK prior to start-up. Moderate damage, down two weeks.
2. Unit shutting down, washing out BL ring header, gun left in furnace resulting in major damage requiring five months of downtime. Event led to BLRBAC recommendation to install BL gun gates which are interlocked to the header wash logic. Major damage, down five months.
3. Lost cooling water flow to the spouts (for some time?) and when reestablished a mild explosion occurred with minor damage. Event led to BLRBAC recommendation to refrain from putting water back into a spout once it has been lost. Minor damage, downtime unknown.



Recent RB Explosions (S-W)

4. Operating normally, explosion occurred. Rear wall tube failure due to corrosion at membrane. Defect not picked up through previous NDT efforts. Event led to BLRBAC recommendation to NDT test at three points at each site (crown and two at membrane). Also, use composite tubing on RB's higher than 600 psig. Major damage, down five months.
5. Restart of RB following downtime to repair ESP for gen section tube leak. While down changed out the FW control valve. On start-up having trouble controlling the FW, RB tripped on low drum and turbine driven FWP tripped. Started the motor driven FWP which is 1/2 capacity, defeated low drum trip brought RB up. 20 minutes later FD fan tripped on high furnace pressure, heard loud noise followed by a rushing sound. ESP'd within three minutes, screen tube rupture. Event led to company developing a companywide RB operator training and testing program. Their program was later given to the AF&PA. Major damage, down five months.



Recent RB Explosions (S-W)

6. Limited information due to severity of event...crews suspected a leak, called superintendent, delay of 30 minutes while waiting for him, they continued investigating, severe explosion involving fatalities. RB a total loss and Mill shutdown permanently. Extreme damage, Mill down permanently.
7. Unit operating for about two months after a month long outage to replace the gen bank. High furnace pressure trip, restarted fans and relit. Heard a hissing noise and ESP'd. 11 minutes later a second more severe explosion, followed by a third more severe explosion. Ruptured screen tube. Found chemical attack on tube potentially from previous retube job chemical cleaning or foreign material left in boiler resulted in inhibited circulation and steam blanketing. Moderate damage, down two months.
8. RB tripped on high furnace pressure. Operators restarted unit and it exploded. Gen section tube sheared at mud drum (near drum corrosion), thrust into furnace, hung up on a SH tie and hosed the bed with water. Moderate damage, down five weeks.



Recent RB Explosions (S-W)

9. Two months earlier unit was down to repair a rear wall tube failure at the smelt line—ESP'd with no explosion. At that time found ≈ 200 thinned tubes which were replaced. The unit had a history of long layups with no fireside cleaning. Difficulty performing effective NDT near membrane. While shutting down for scheduled maintenance firing oil and heard a loud bang. Saw dark bed area, moisture at PA ports and water leaving the spouts. Tried to ESP but system and fans tripped due to heavy building vibration when explosion occurred. Reset ESP and initiated 17 minutes later. Split on bottom of one of spouts (in service five months). Minor damage, down two days.
10. Incomplete information, could also be fuel related. Operating normally with six BL guns, four S/U oil and three load oil burners. BL divert system in bypass (needing to circulate BL to DCE?). BL burning poorly with ineffective pressure and temperature control attributable to secondary BL heater blowing through. Pulled BL from boiler, got unit under control and when adding BL back in explosion (low BL solids/pyrolysis gas/S-W?). Moderate damage, down one month.



Recent RB Explosions (S-W)

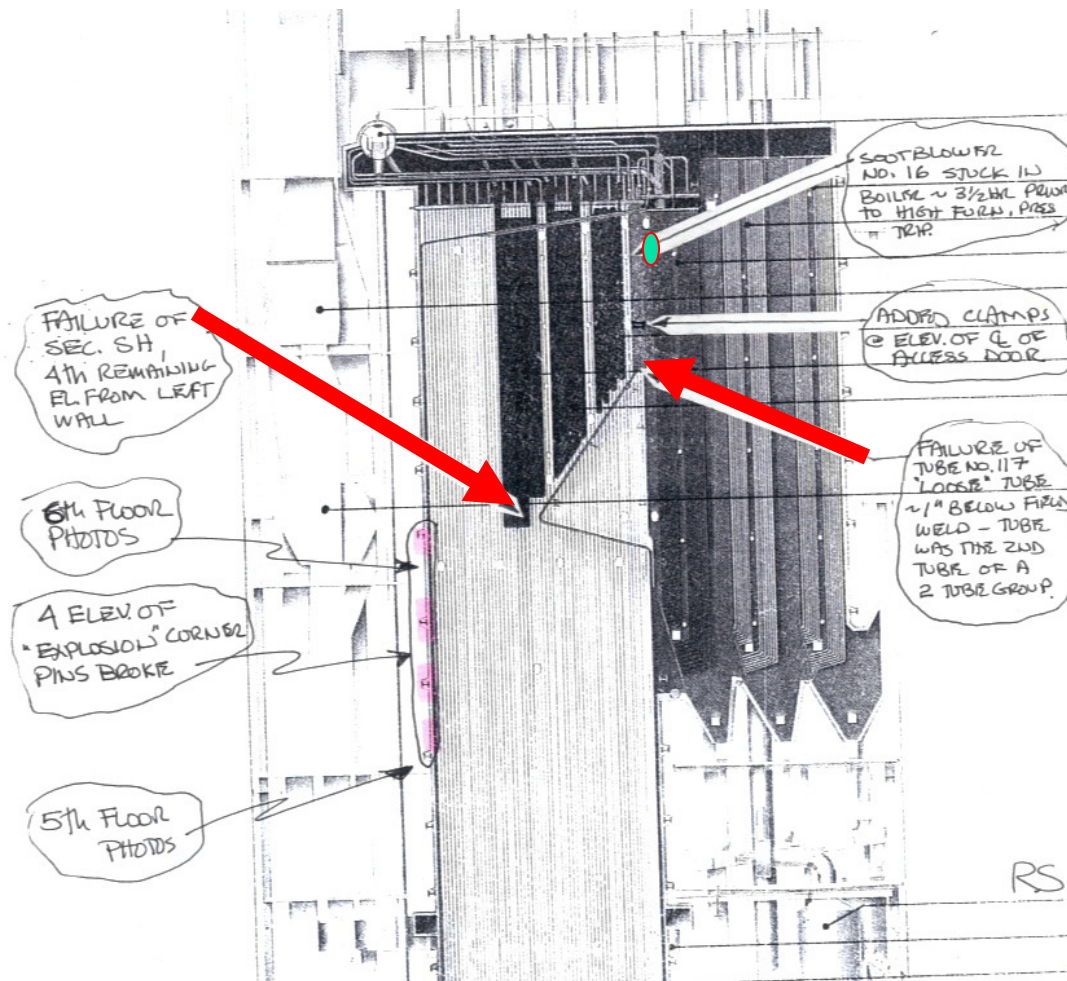
11. No information on event. Extreme damage, fatalities and mill permanently shutdown.
12. Stopped firing BL due to inventory. Did a BL ring header wash and left gun in. Explosion. Major damage, downtime unknown, Mill has since S/D.
13. Trouble getting BL through the DCE, solids dropping and BL divert conducted. Load burners tripped on low drum level. Conducted a hot restart and heard a rumble then an explosion. Two floor tubes had failed and ten others were blistered (water chemistry issue?). Had been possibly leaking for up to one month before event. Moderate damage, downtime unknown.
14. Water washing the boiler without first sufficiently cooling the bed. Event led to BLRBAC recommendation to cool the char bed to <800 °F and probe temperature with thermocouples prior to water washing. Moderate damage, downtime unknown.

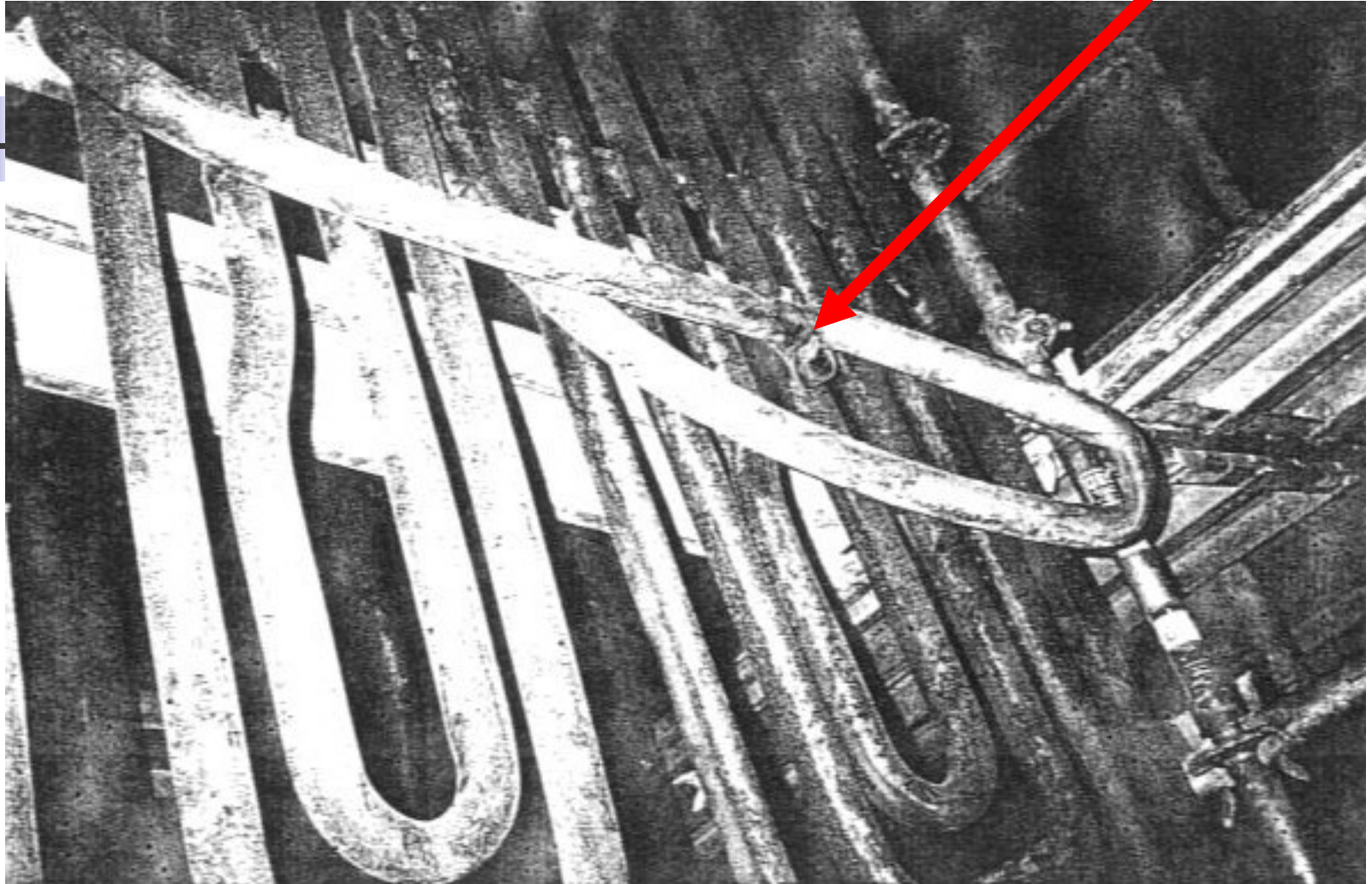
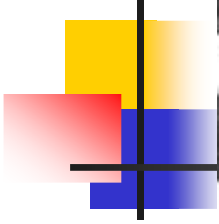


Recent RB Explosions (S-W)

15. Sootblower stuck about mid-travel in the rear wall screen lane. Mechanics delayed in responding and eventually removed the sootblower from the boiler. High furnace pressure trip, drum level low and using 250 mpph FW to maintain level. Got back on line burning BL, furnace pressurizing and found ruptured SH tube. Burning out bed for shutdown (steam 240 mpph, FW 450 mpph) and discovered something wrong. Open RB rapid drains but, did not ESP. 15 minutes later FW >700 mpph, tripped two motor driven FWPs but, the turbine driven pump required a manual local trip. Explosion. The walls bulged and explosion corner opened up. Minor damage, down one week.

S-W Event #15 Pictures

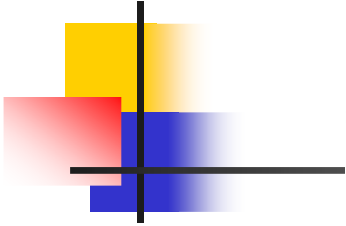






SEC. SIX FAILURE IN 4TH REMAINING EL. FROM LEFT WR
TUBE NO. 15 NEAR LOWEST BEND IN FULLY RADIANT SECTION.





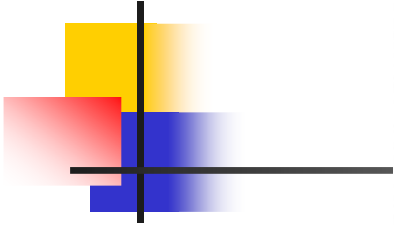
pen
pow
15
B
BS

LEFT
- ABOVE
ECK
DOORS -
ASTM
BROKE
A ELEV.
STAYS,
DOT
WALLS
CORNER.



6TH FLOOR





5th Floor Front Left corner

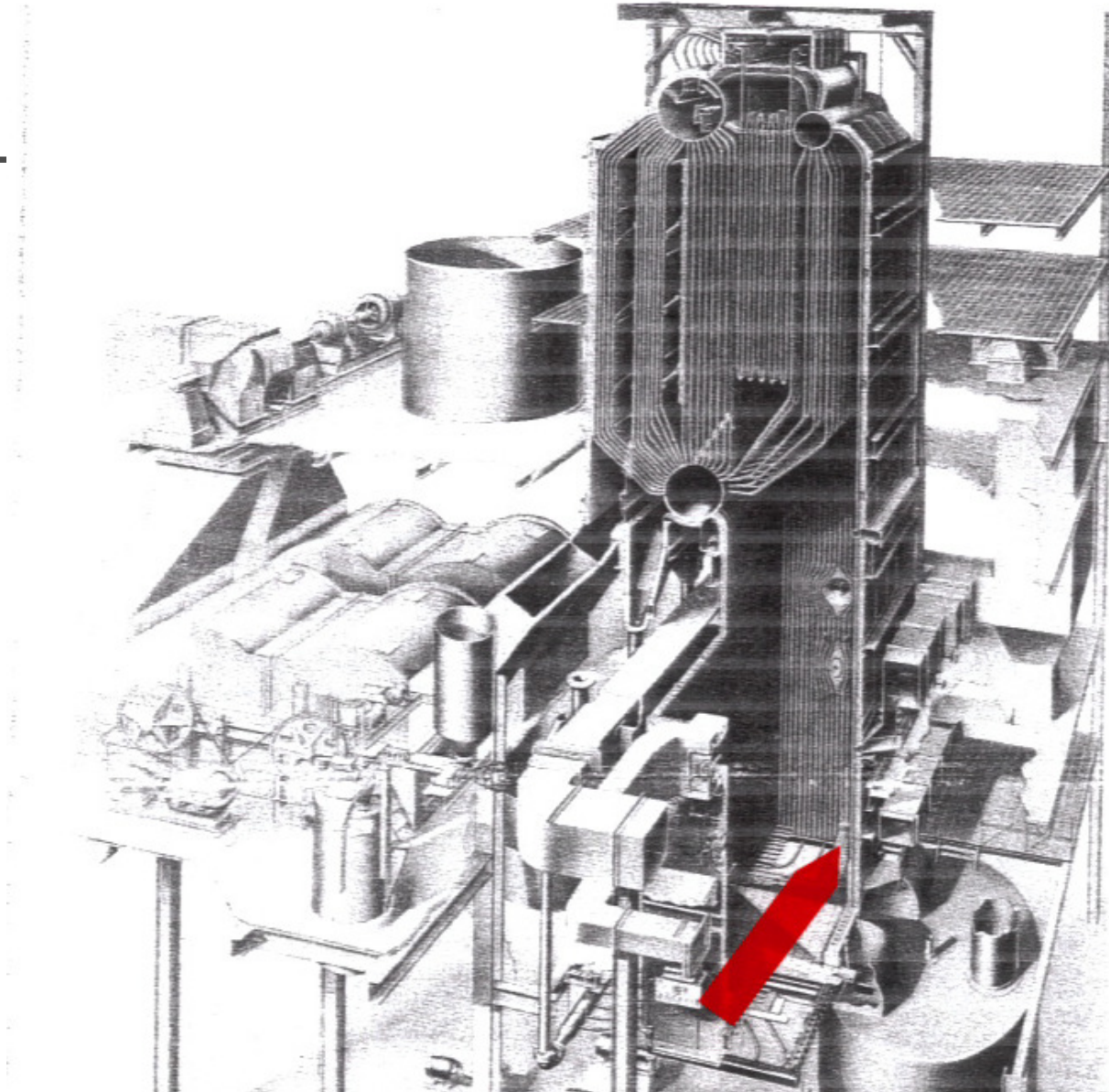
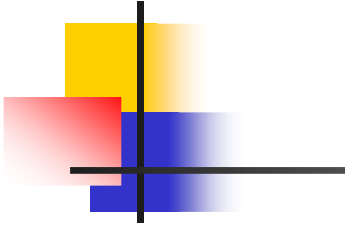


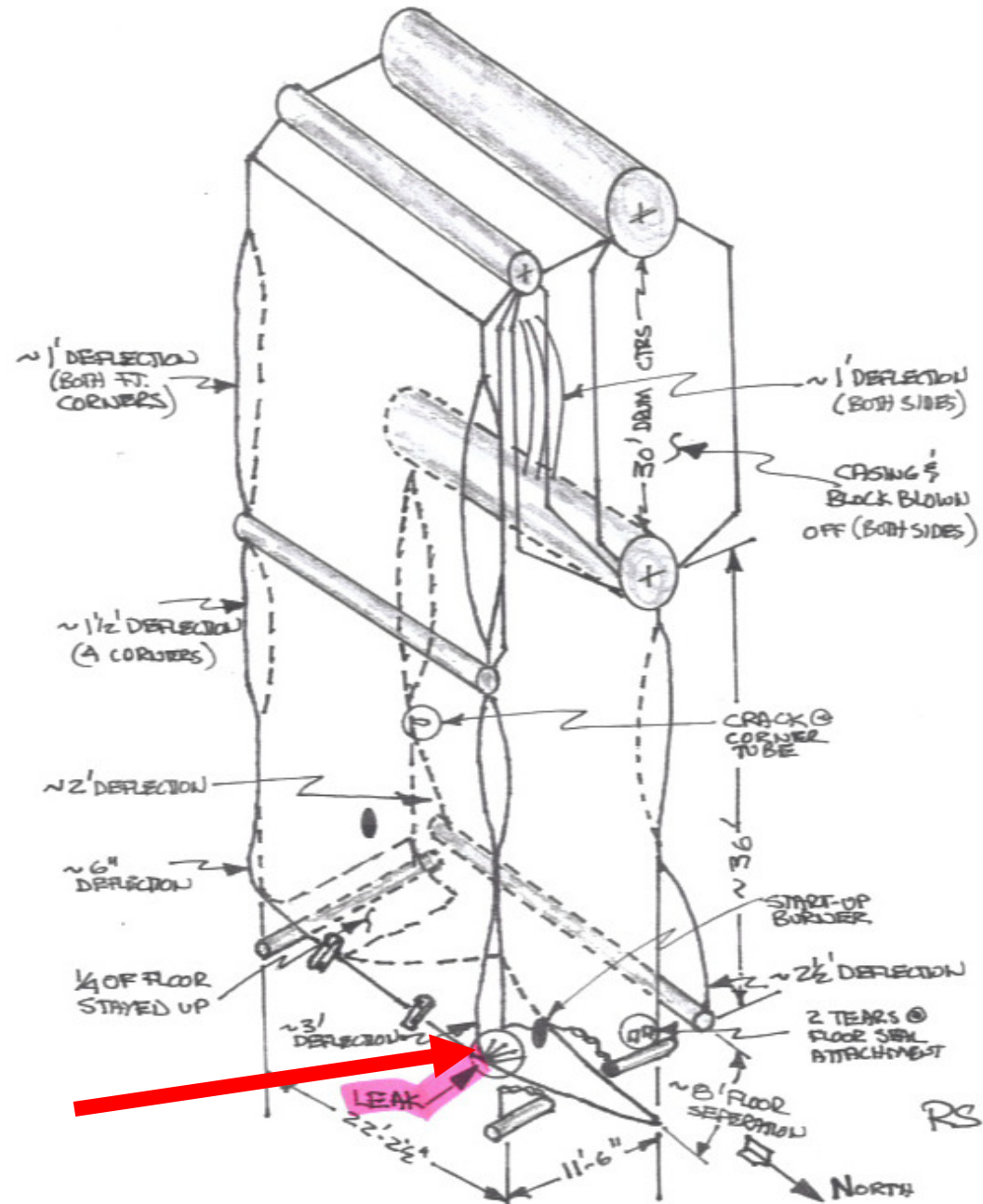
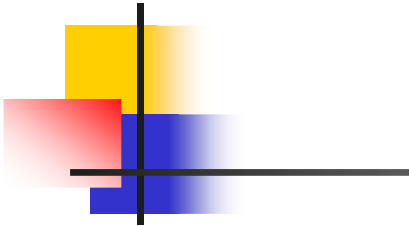


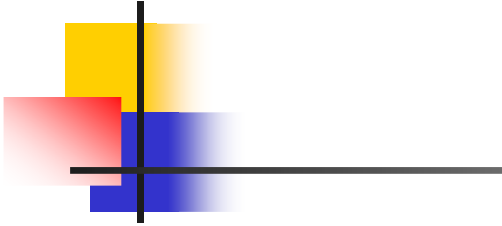
Recent RB Explosions (S-W)

16. ID fan speed increasing, drum level dropping, FW control in manual 96% open to reestablish drum level and FW back in auto. MFT for high furnace pressure, FW in auto and drum level dropping. Reestablished drum level and attempting restart when two loud explosions heard. ESP'd. PLC fault drove SB in for 3.5 hours and sheared a gen section tube at steam drum. Replaced floor, beams, all buckstays and some wall panels. Major damage, down four months.
17. BL unstable burning, noise at char bed from BL gun slag, walkdown and no leak detected. 7.5 hours later unit trips on low drum, bring back on line. Two hours later low drum trip, ID fan speed has increased by 30% and FW open 100% in manual. Reestablish drum, light an oil burner, loud explosion and ESP'd. Leak at right floor to sidewall seal plate (DWD ≈ 90 g./ft.²), all corners opened one to two feet (no explosion corner), floor separated ≈ 8 feet and the building steel was damaged. Extreme damage (fatalities and serious injury), Mill permanently shutdown (900 people).

S-W Event #17 Pictures

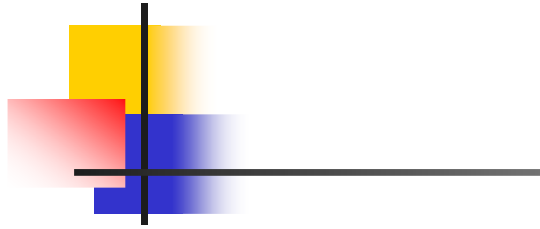






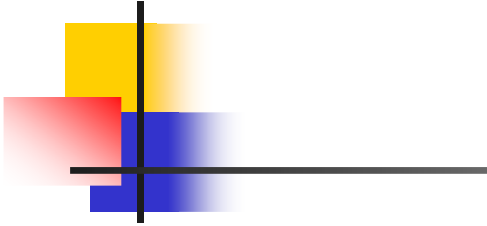
6TH FL.





STAF

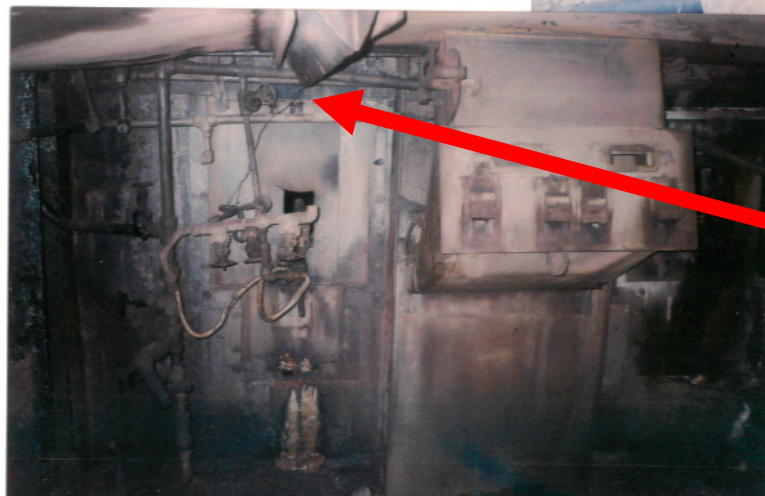




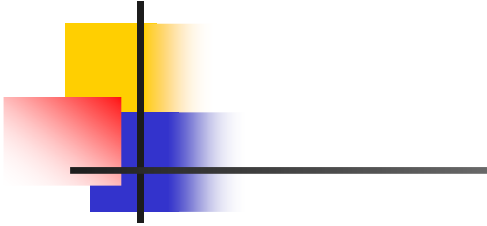
MEZ. ABOVE
2ND FL



MEZ. ABOVE
2ND FL



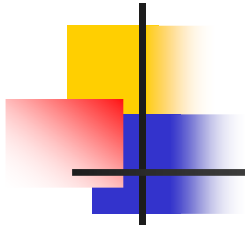
1ST FL @
START-UP BUFFER



1st FL

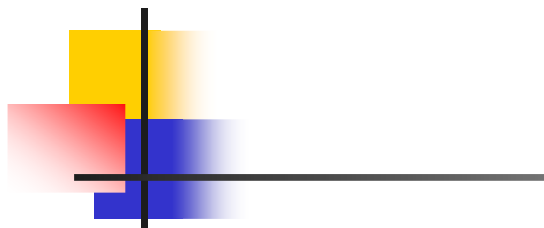


GROUND FL.

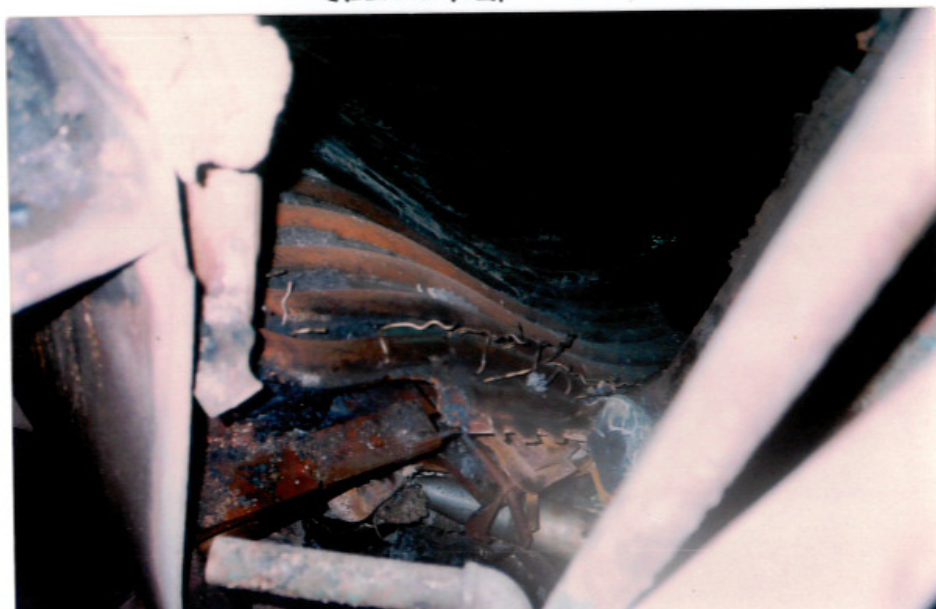


GROUND FL.

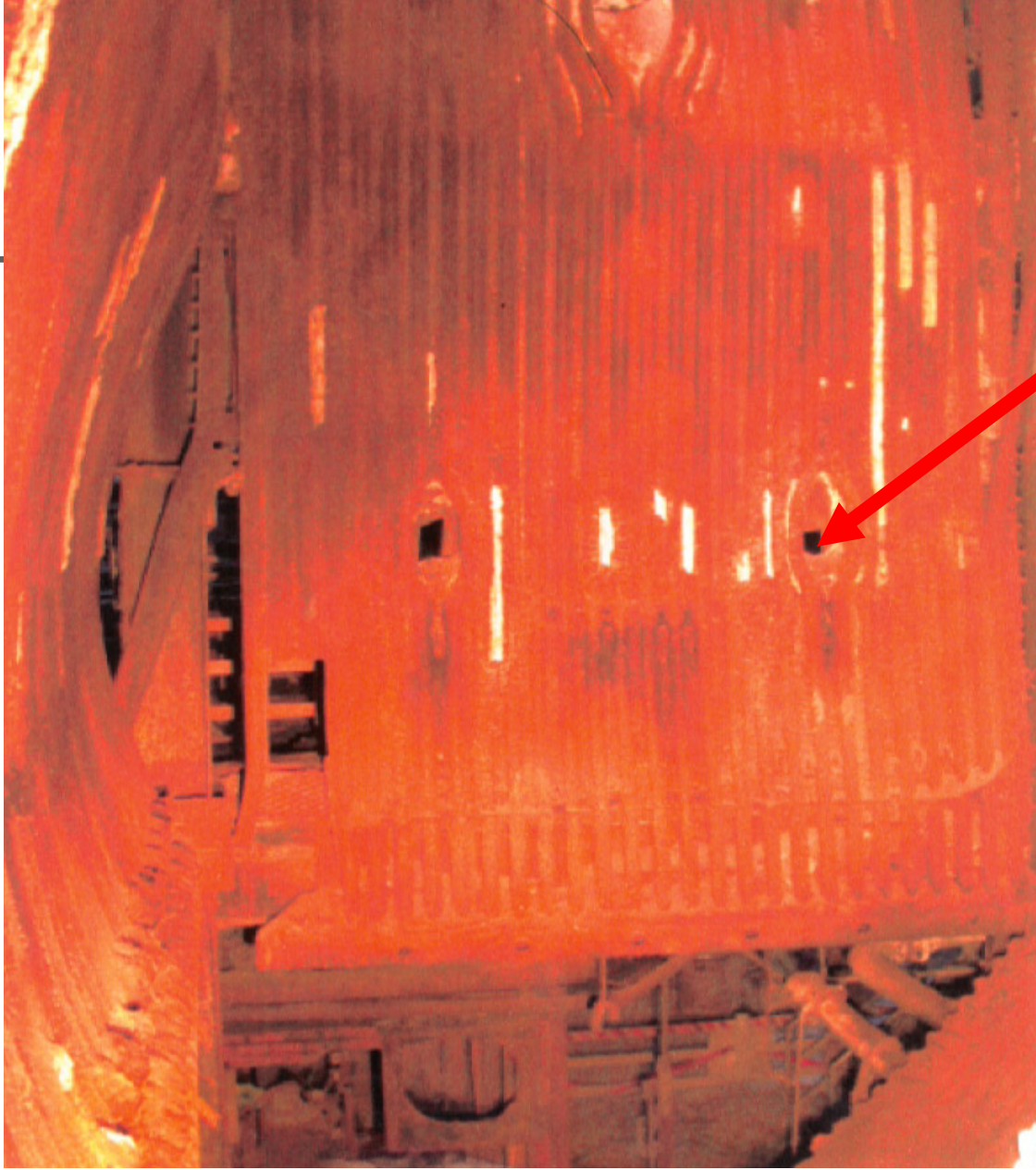
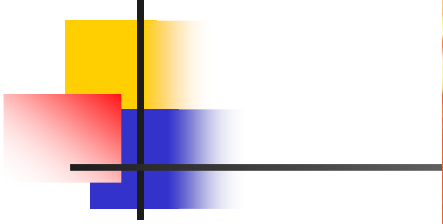


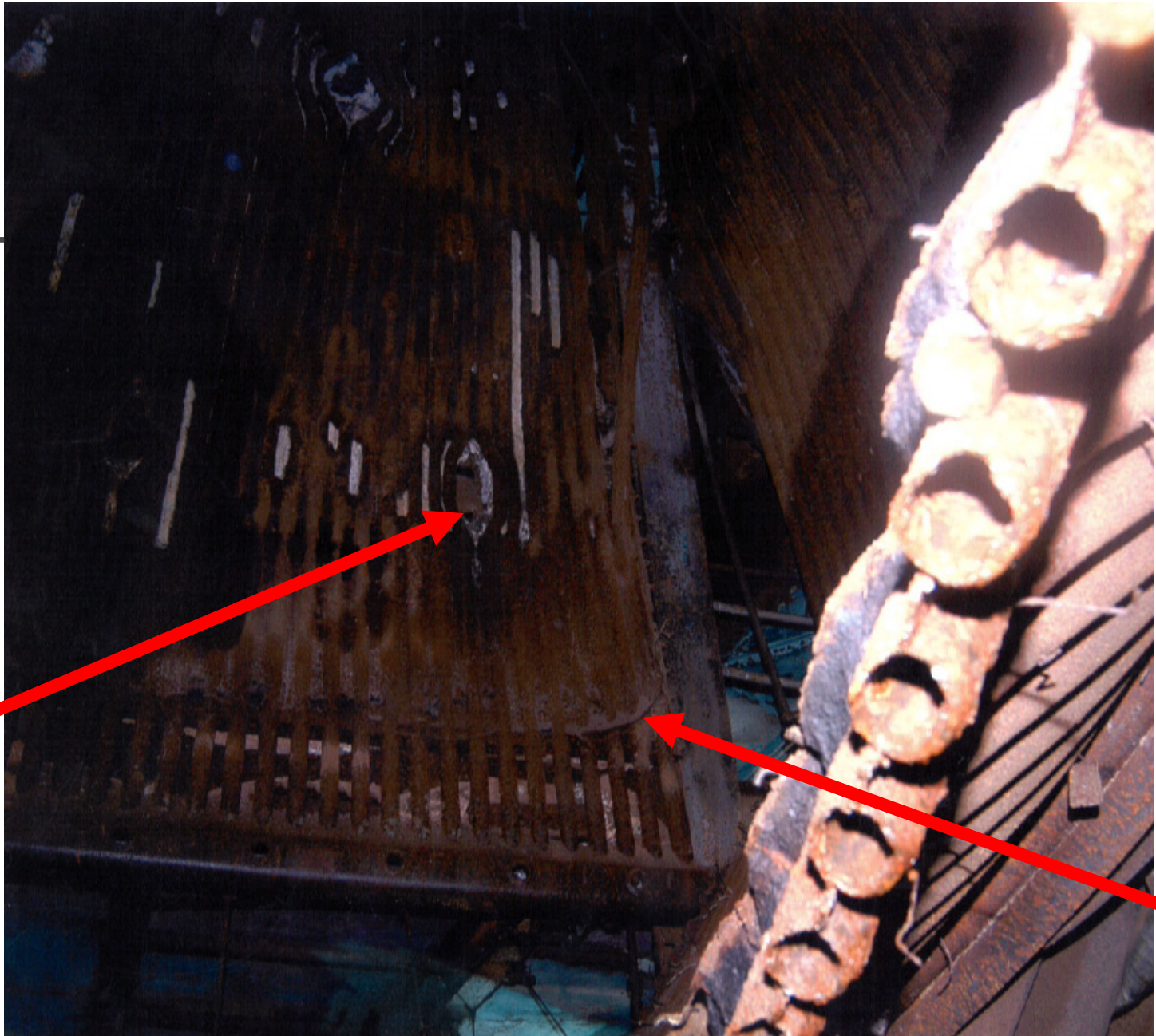
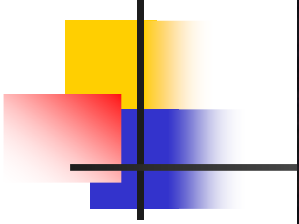


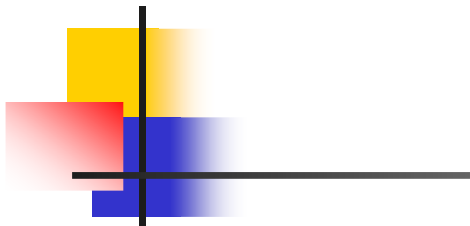
GROUND FL.



1ST FL.





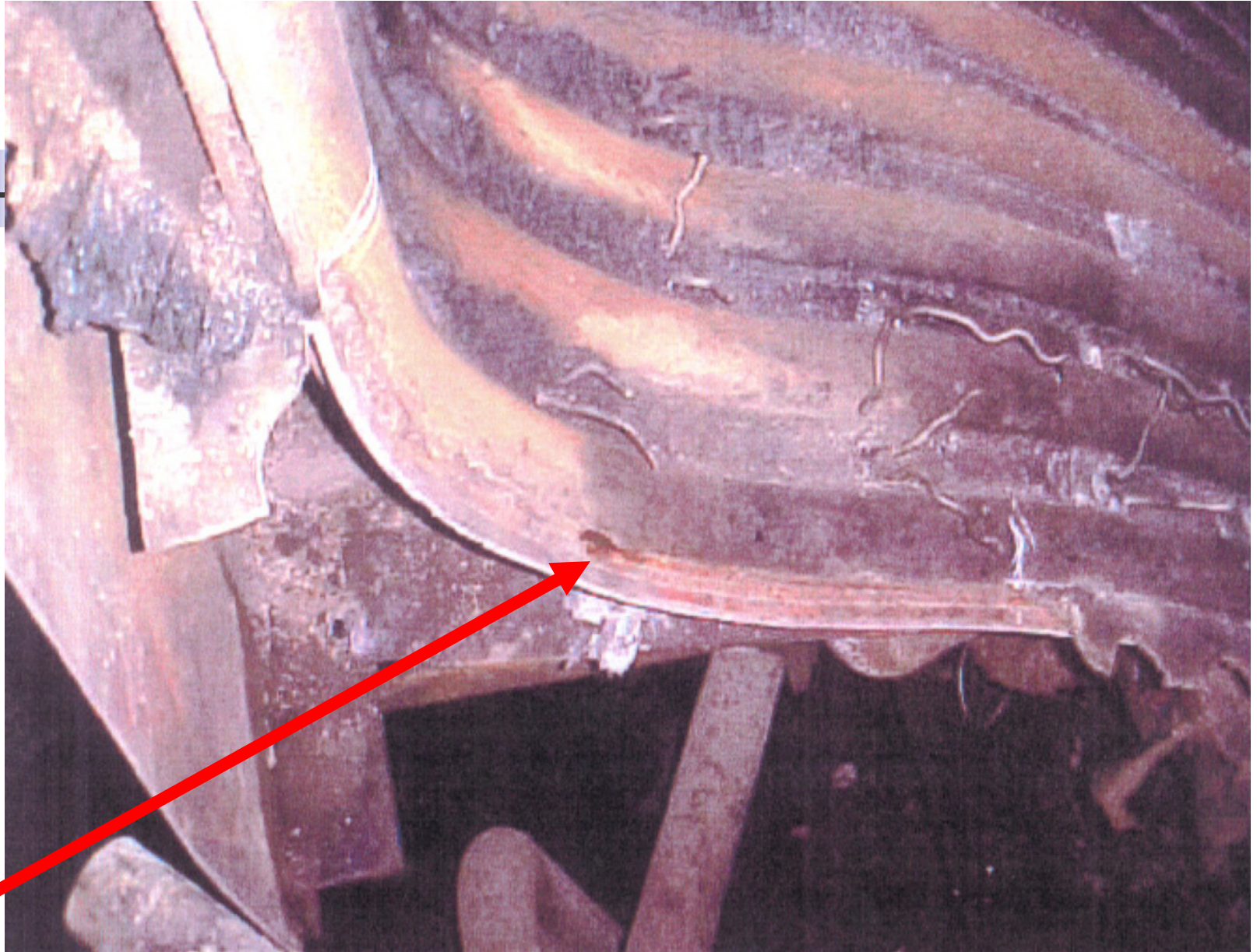


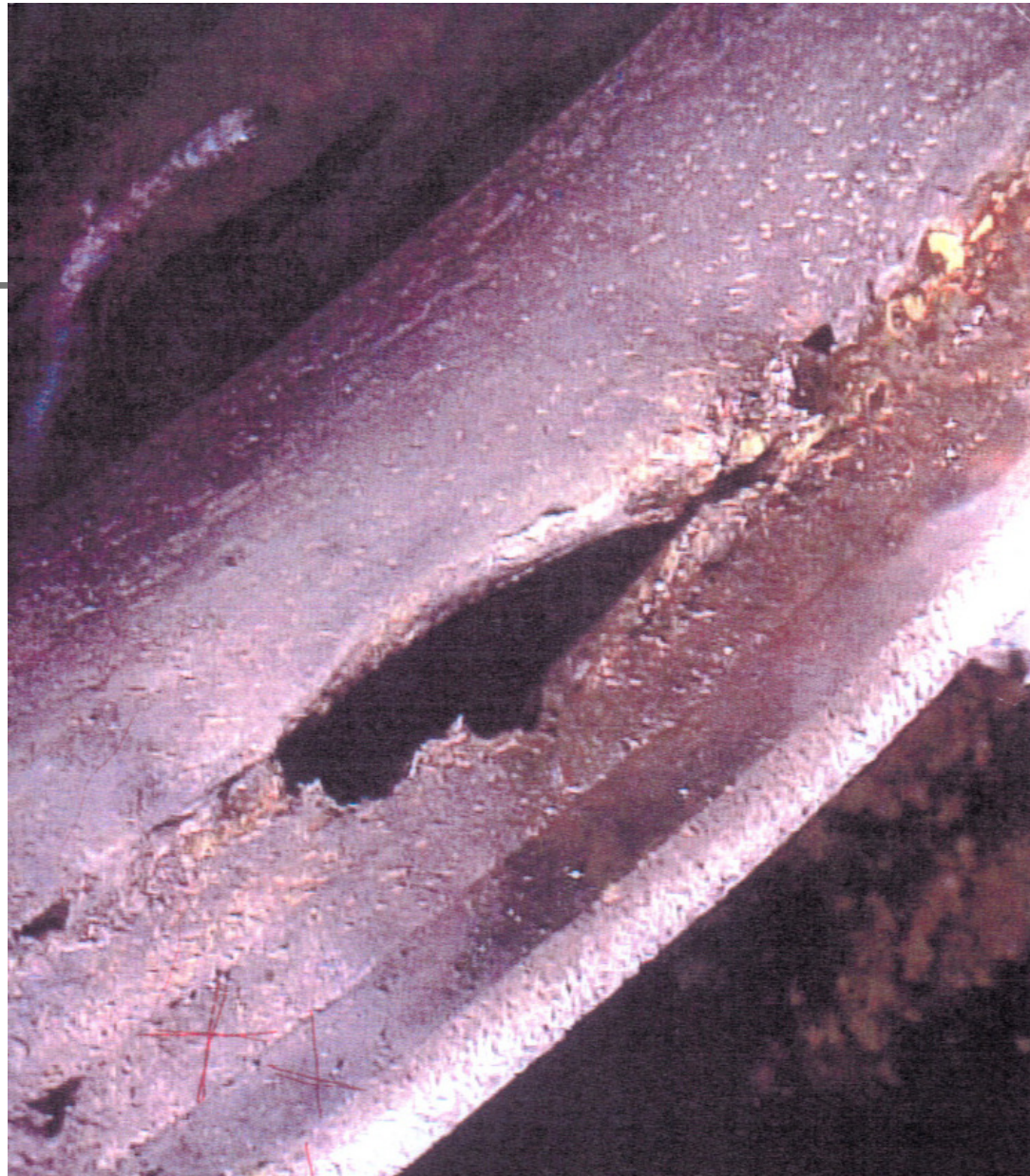
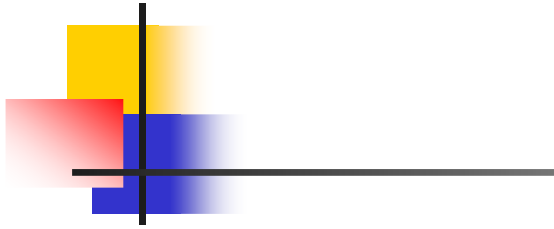
RT. REAR CORNER SIDEWALL TUBES

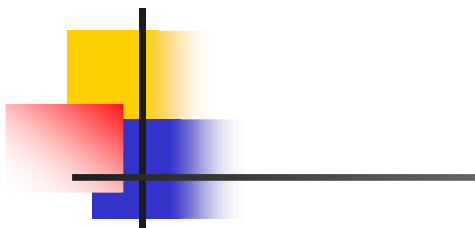
LEFT REAR CORNER
REAR WALL TUBE

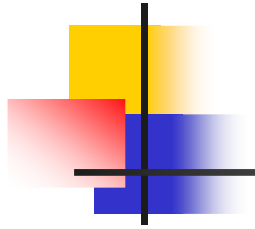


RT. FRONT
CORNER
FLOOR
TUBE



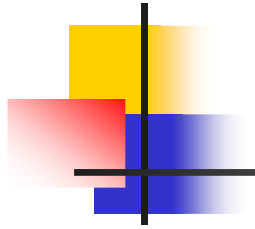






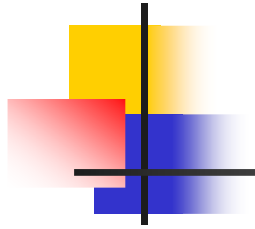
Recent RB Explosions (S-W)

18. The primary air ports had been blacking out, checked it out and declared OK. Next shift heard a pop followed by an explosion. ESP'd. Leak at RHSW PA level. Replaced four tubes. Last chemical cleaning 22 years prior. DWD factor? Minor damage, down four days.
19. Had been operating normally when a large concussion was felt and an explosion heard. Saw smoke out of the spouts and smoke throughout the building. Attempted to ESP, pressure did not drop so shutdown equipment manually and this was followed by a second more violent explosion. Believe a large amount of ash slag fell from the roof and sheared screen tubes. Major damage, down one month.



Recent RB Explosions (Pyrolysis Gas)

1. Start-up burner ignited pyrolysis gas from BL being sprayed into boiler while not burning. Event led to BLRBAC recommendation for start-up logic requiring a minimum hearth heat input (steam flow or number of start-up burners in) prior to permitting BL firing. Moderate damage, downtime unknown.
2. Primary and secondary combustion air fans tripped which initiated a MFT. BL continued to fire due to obsolete C-E logic to quench the bed with BL after MFT still in effect, even though thought by Mill personnel to have been previously removed. RB purged for 5 minutes and when the first gas burner was lit a slight explosion occurred resulting in bulged walls. Minor damage, down 4 days.
3. RB on line and had a high furnace pressure trip. Conducted a hot restart



Recent RB Explosions (Pyrolysis Gas)

3. RB on line and had a high furnace pressure trip. Conducted a hot restart with difficult drum level control. Readmitted BL and explosion occurred. Unit ESP'd. Question whether the BL divert system was available and functioning normally. Minor damage, down 10 days.



Recent RB Explosions (Comb. Gas/Aux Fuel)

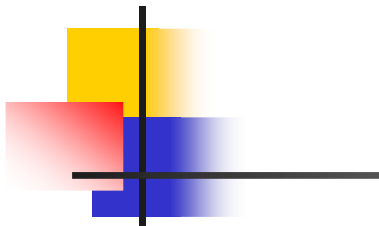
1. RB was being fired on BL and the BL solids tests done every 30 minutes were within the acceptable range. The BL divert system was bypassed at this time due to a third RB off line for a SH tube leak. BL flow interrupted (pump KO?). BMS logic designed such that if an ignitor pilot is established prior to <25% outlet steam flow, no purge is required. Several attempts to light oil burners failed, so tried BL. Explosion. ESP failed to activate, manually drained boiler. Found WBL backed up from BL dump system into cascade DCE. Moderate damage, down two months.

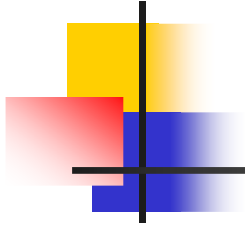


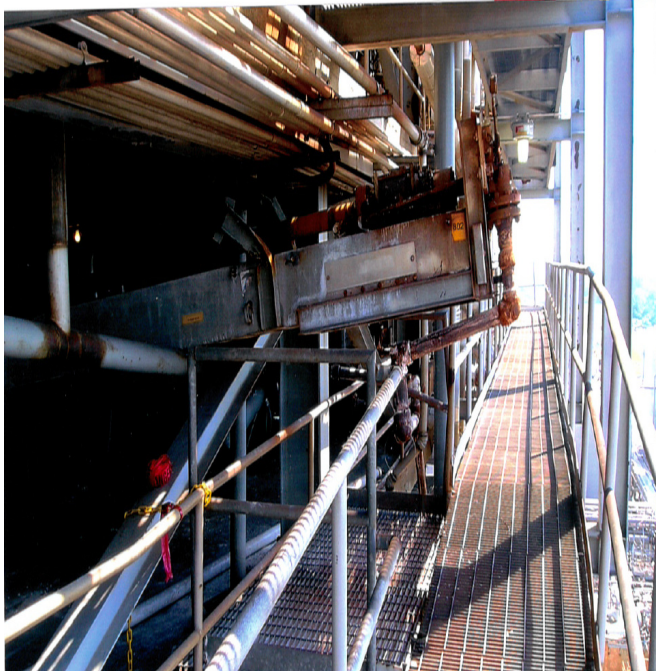
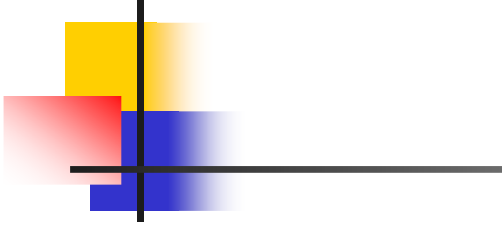
Recent RB Explosions (Comb. Gas/Aux Fuel)

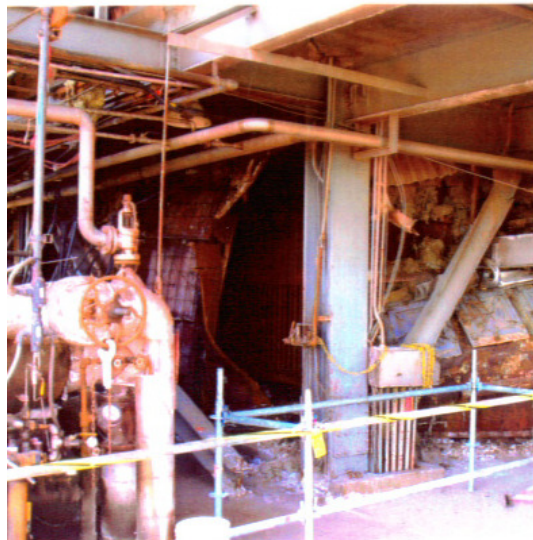
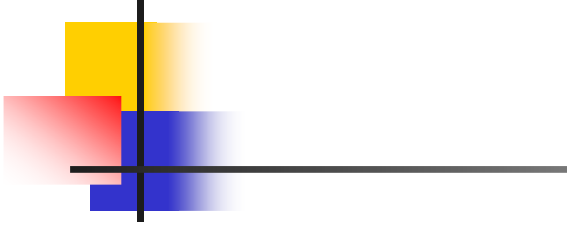
2. New unit in the process of being commissioned. Firing natural gas, had never seen BL firing. BMS not fully commissioned, e.g., flame scanners not tuned, maximum gas pressure and trip not operating properly, etc. Firing four LBs to support Mill load and steam header swing caused 3 of 4 LBs to trip. Since the one in service LB was on flow control as each LB tripped more gas was added until the last LB was beyond its design capacity resulting in unburnt fuel accumulation which exploded when the adjacent LB was relit. Unit has an explosion corner. Moderate damage, down two months.
3. Cold outage, power boilers down, package boiler in to run 400# fans with 150# steam for recovery start-up. Unit not up fully with stable headers and sent 80# steam to the evaps, explosion. Start-up burners have Class I ignitors (20% capacity) with separate combustion air and no main flame monitoring. Starved fans, speed dropped and combustibles accumulated. Extreme damage (one fatality and multiple burns), down eight months.

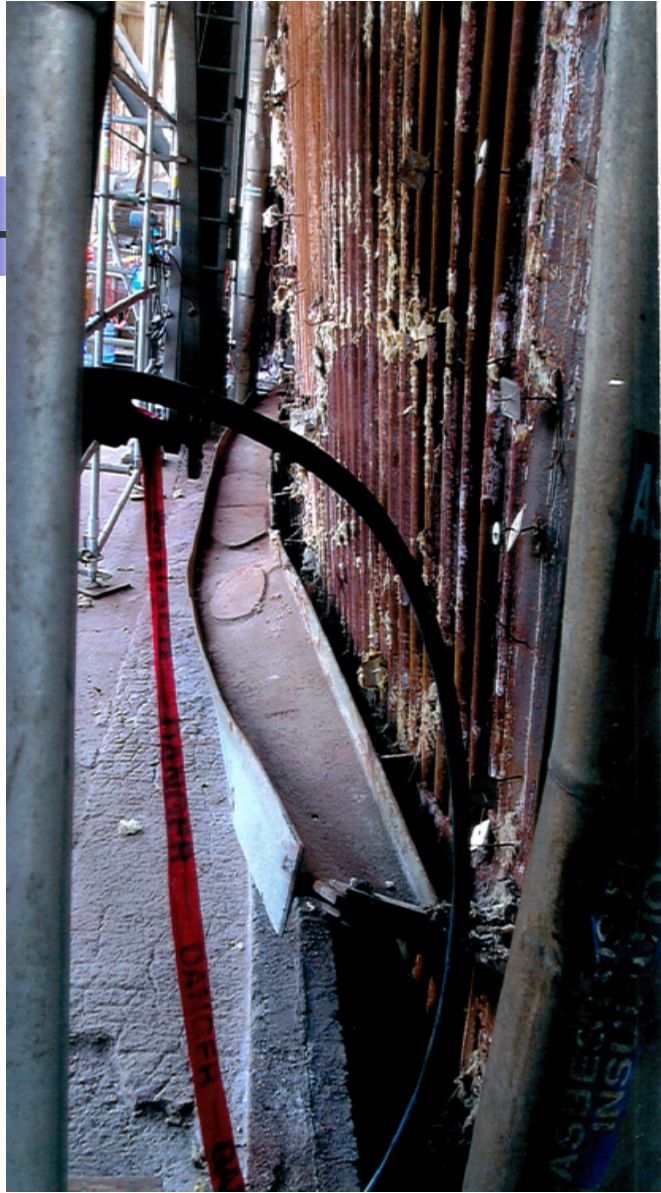
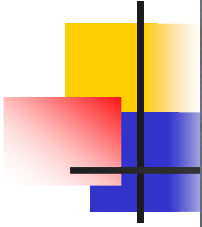
Comb. Gas/Aux Fuel Event #3 Pictures













RB Explosion History Conclusions

25 RB Explosions over 28 years (1984-2012)
of those events...

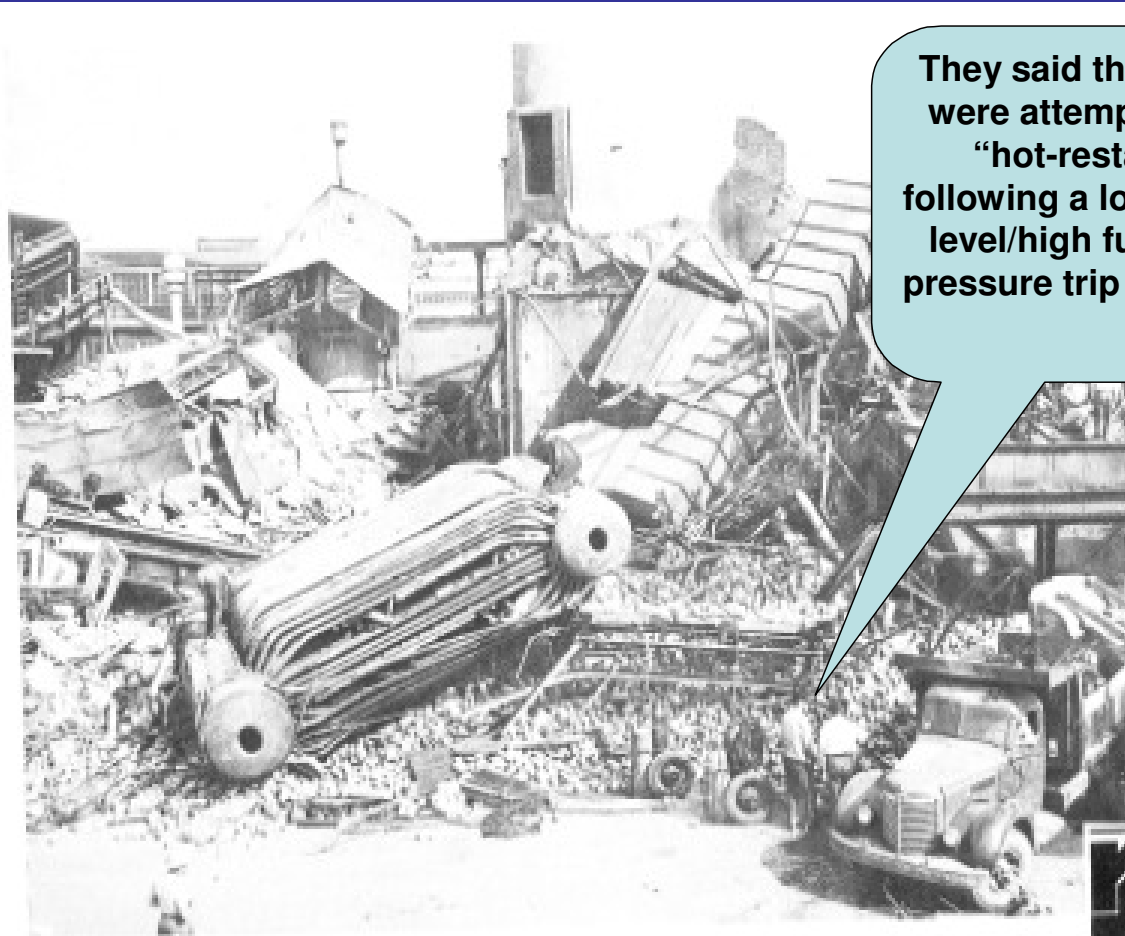
- 18 involved mistakes/lapse of judgment
(training, expectations, procedures, operators not empowered, production pressures, etc.)
- 9 involved hot restarts
- 5 led to BLRBAC recommendations
- Damage
 - 6 minor
 - 9 moderate
 - 6 major
 - 4 extreme



RB Explosion Data Analysis

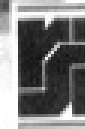
- The data clearly shows that there are **3** steps leading to the majority of recent catastrophic RB explosions with severe damage:
- Eliminate any step (link in the failure chain) and an explosion does not occur!
 - 1st Step--A **large pressure part leak** occurs.
 - 2nd Step--**RB operators do not recognize or react properly to the indications** of a major pressure part leak.
 - 3rd Step--**RB operators proceed into a “hot restart”.**
 - **A smelt-water *EXPLOSION* occurs.**

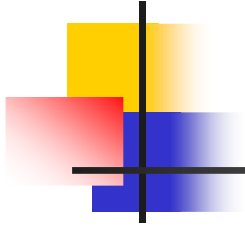
RB Hot Restart



Courtesy Mutual Boiler and Machinery Insurance Co.

They said that they were attempting a “hot-restart” following a low drum level/high furnace pressure trip when...





What Operators Can Do

(To Reduce the Chance of a RB Incident)

- Be sensitive to the dangers of a hot restart
- Use all leak detection tools
- Participate in Audits
- Utilize BLRBAC and AF&PA resources



RB Production Pressure

- This is a major factor in quickly attempting a **HOT RESTART** following a RB trip.
- Half of RB explosions occur during **hot restarts**.
- **Stop** and **ensure** there are no pressure part leaks prior to a hot restart.
- Other industries also experience these same **production pressures**.



Pressure Part Leak Detection

- Although much reduced from previous years, **pressure part leaks are still the major cause of smelt-water explosions** that damage RB's.
- **Hot restarts** (with leaks) led to \approx half of the explosions.
- BLRBAC Incident Reports consistently show that \approx **2/3 of all pressure part leaks are 1st detected at the boiler by field checks**, before RB instrumentation detected the signs of a leak.



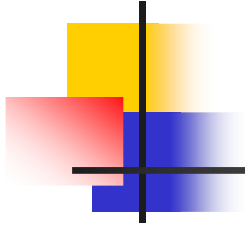
Leak Detection at the Boiler

- Puffing or blowback
- Blowing or hissing sounds with the SB's off
- Dark spots in the char bed
- Unusual noise from the char bed
- Water, steam, or damp spots on lagging/casing
- Water or dampness in the ash hoppers or conveyors
- Water or dampness in the PA or SAr ports or ducts
- Water overflowing the air duct low-point seal pot



Leak Detection from Control Room Instrumentation

- Unexplained decrease in CBD conductivity or PO_4 residual
- Unexplained increase in ID fan speed
- Unexplained high furnace pressure or trip
- Unexplained low drum level or trip
- Erratic draft readings
- Unexplained decrease, imbalance, or erratic temp. indications in the boiler bank or economizers
- Sudden increase or decrease in drum level
- Significant changes or differences in the steam & FW flow rates
- High motor loads or trips of the ash feeders or conveyors
- Unexplained drop in BL % solids



What Operators Can Do

(To Reduce the Chance of a RB Incident)

- Follow protocols, procedures and be empowered to act (management owns the larger part of this)
- Be aware of five ways to wreck a RB



Five Ways to Wreck a RB

1. Don't Protect the Superheater
2. Don't Protect the Large Economizers
3. Don't Follow the Start-up Curve
4. Provide Poor Feedwater & Boiler Water Quality
5. Don't Check for a **Pressure Part Leak**
BEFORE Attempting a **HOT RESTART**



1. Protect the Superheater

- **Hydro;** Backfill with demineralized water
- **Start-Up;** Boil out elements before flue gas $>900^{\circ}\text{F}$
- **Operation;** Limit load, balance firing, attemperate steam temp. to operate within allowable SH metal temps.
- **Trip or Shutdown;** Open SH vent to ensure steam path cooling until flue gas is $<900^{\circ}\text{F}$
- **Chemical Cleaning;** Backfill the SH between cleaning stages



2. Protect the Economizer

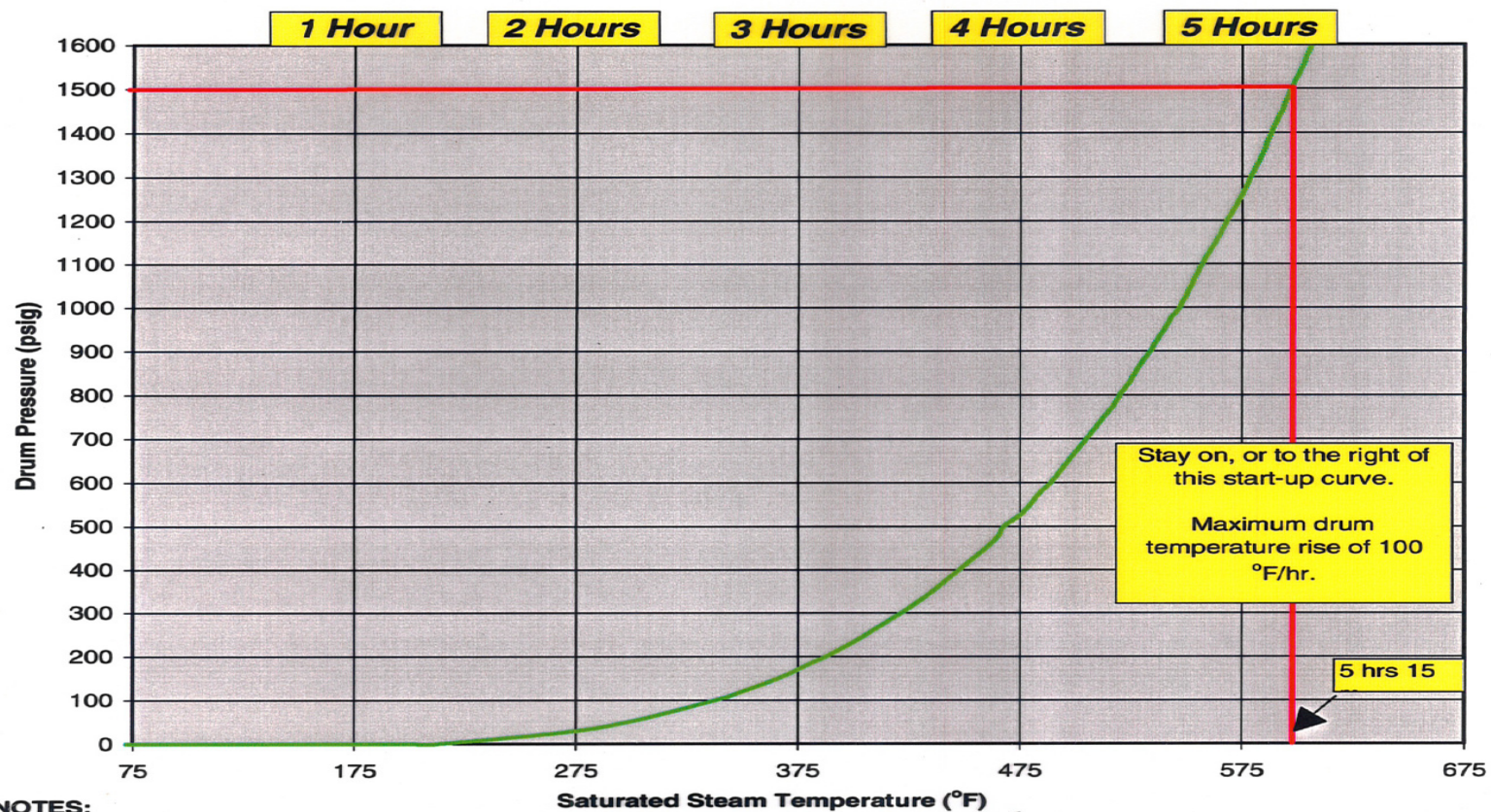
- **Filling;** FW max. temp. is eco metal temp. + 100F.
- **Start-Up;** Stay on the curve; too long can boil the hot economizer. Don't boil Eco2. Keep FW outlet <20F of the steam drum saturated temp.; vent SH or blow down drum enough to cause some FW flow.
- **Water Washing;** Ensure hard salt deposits are washed from between the outer eco elements & the eco sidewall casing.
- **Outages;** Inspect to ensure eco lower header/hopper expansion joints are clean to allow motion.



3. Follow Start-Up, Cooldown, & Hydro Curves

- **Start-up;** Maximum temperature (pressure) rise rate = **+100°F/hr.** (~ 5.2 hrs. 75F→595F[1500#]).
- **Cooldown;** Maximum rate = **-100°F/hr.**
- **Hydro;** Maximum water temperature = **+100°F** above drum or economizer metal temps.
- **Hydro;** Maximum pressure rise & decrease rates:
 - 0→1250# = **+100 #/min.** (normal hydro)
 - 1250#→1875# (1.5 x oper.) = +50#/min.
 - 1875#→2510# (1.5 x design*) = +15#/min.
(major pressure part work)
 - Design pressure = 1675#

1500 psig Start-up/Cool-down Curve



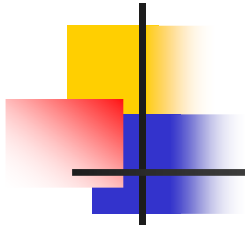
NOTES:

1. Do not exceed 900 °F gas temperature into the superheaters until they have been boiled clear (greater than sat. temp.)
2. Keep the economizer feedwater temperature less than 30 °F of the drum temperature.



4. World Class Water Quality

- Treated Water Quality
- Condensate Quality
- Deaerator Operation
- Feedwater Chemistry—pH, O₂ scavenger, etc.
- Blowdown Control—Silica, Alkalinity, Conductivity



5. Hot Restart (BLRBAC recommendation)

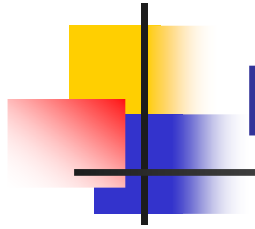
Following a MFT for HIGH furnace pressure *and* a LOW drum level condition:

- An alarm will announce a “*Possible Leak*”.
- DCS will drive FW control valve closed and auto-switch control mode to manual.
- RB operator **MUST** check & verify *no furnace pressure part leak* **PRIOR** to readmitting FW to re-establish drum level.



BLRBAC and AF&PA Recommendations

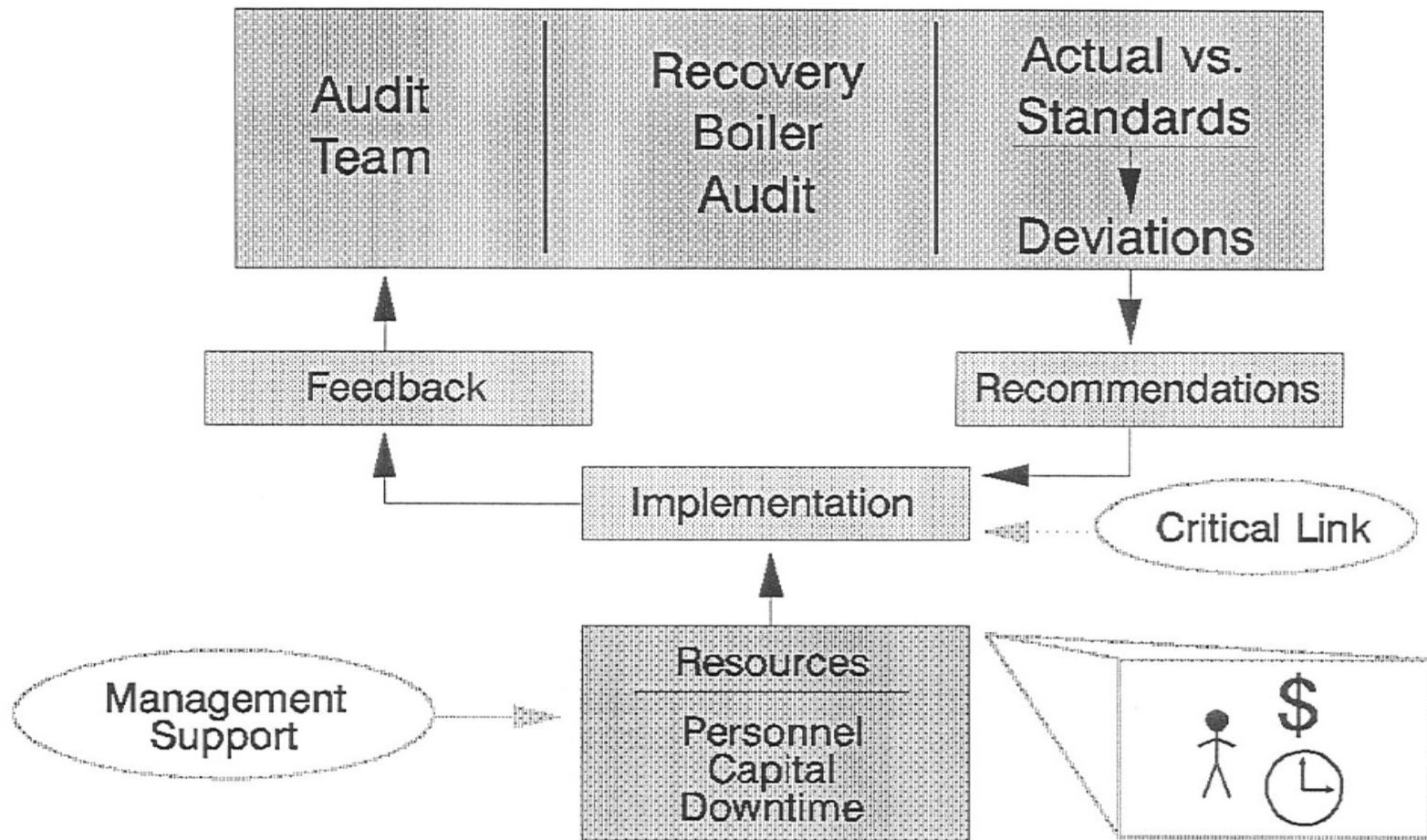
- ESP system
- BL refractometers and divert logic
- Burner management systems
- DCE fire suppression systems
- Waste streams protections
- Liquor gun gate logic



BLRBAC and AF&PA (continued)

- Annual spout replacement and hydros
- Incident reports and audit programs
- RB Operations seminars
- RB Operator refresher training
- Upset/Emergency procedures

Recovery Boiler Safety Audit

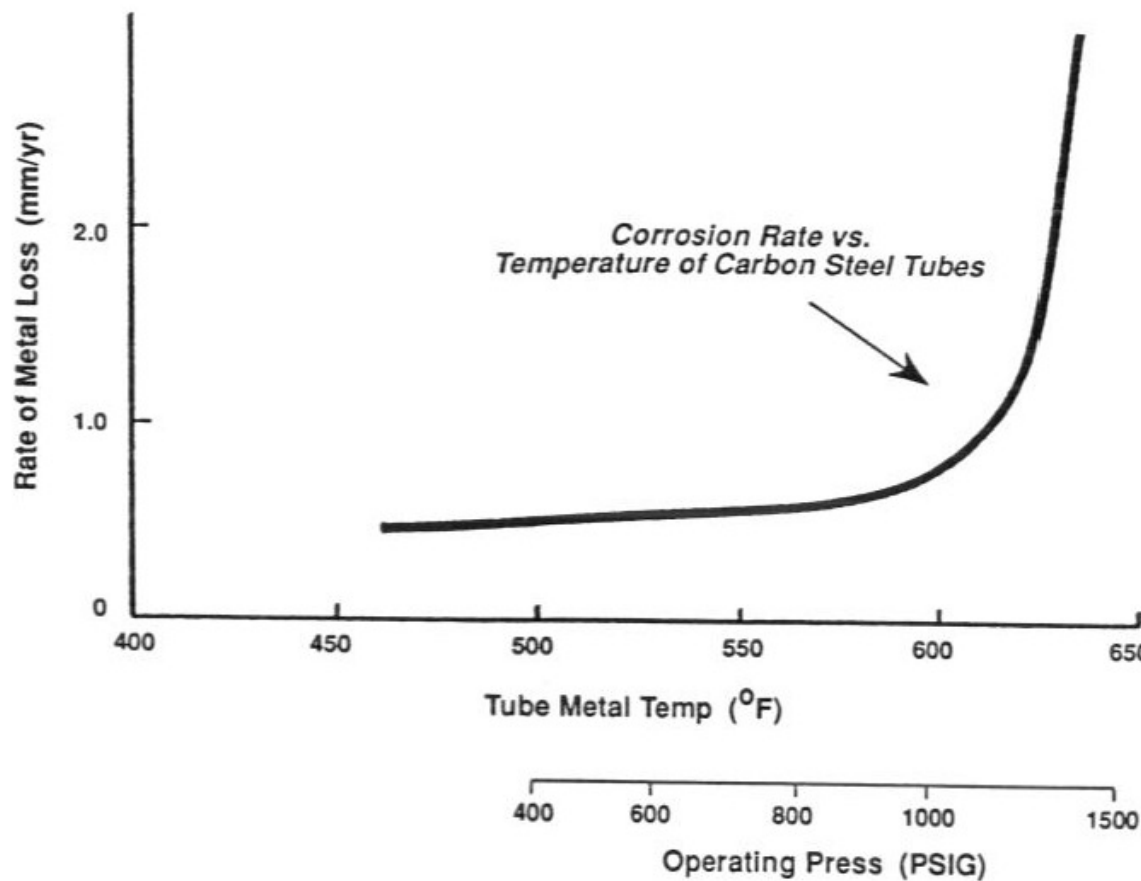




RB Design Improvements

- Mid-furnace explosion relief corners
- Improved SH metallurgy (higher temp.)
- Improved SH tie-clip & roof seal designs
- SWC for SH attemperation vs. FW
- Improved FW & condensate treatment; RO, polishers, on-line sensors, etc.
- Single-drum vs. 2-drum w/rolled tubes
- No furnace screens or improved screen design
- Improved circulation design, corners, etc.
- Greater margins for circulation stability

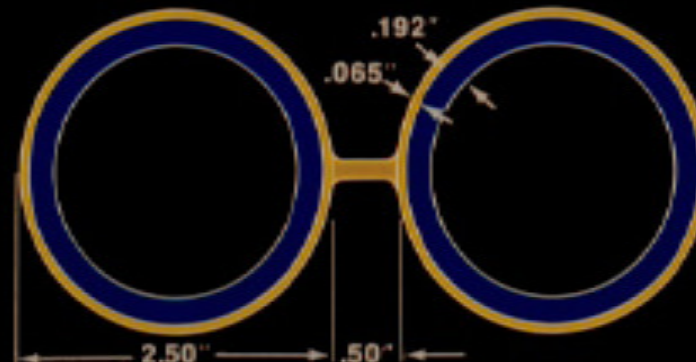
RB Lower Furnace Corrosion Rate vs. Pressure (Temperature)



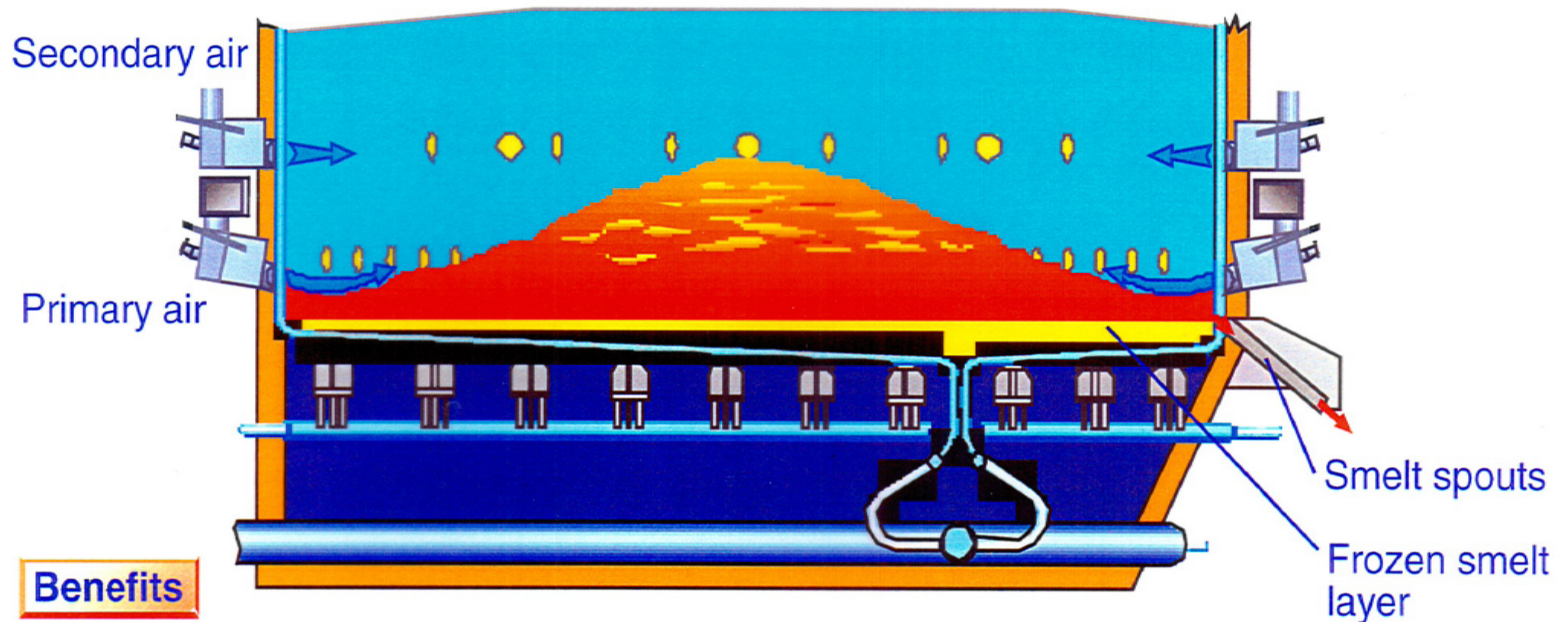
Corrosion Protection

Composite Tube Membrane Wall

Tube OD	2.50 in.
Thickness	0.257 in.
Base (Carbon Steel)	
Material	SA 210A1
Thickness	0.192 in.
Outside Layer (Stainless)	
Material	Aisi 304
Thickness	0.065 in.
Maximum Design Pressure	2100 PSIG
Membrane	
Material	Stainless Steel
Thickness	0.160 in.
Width	0.500 in.



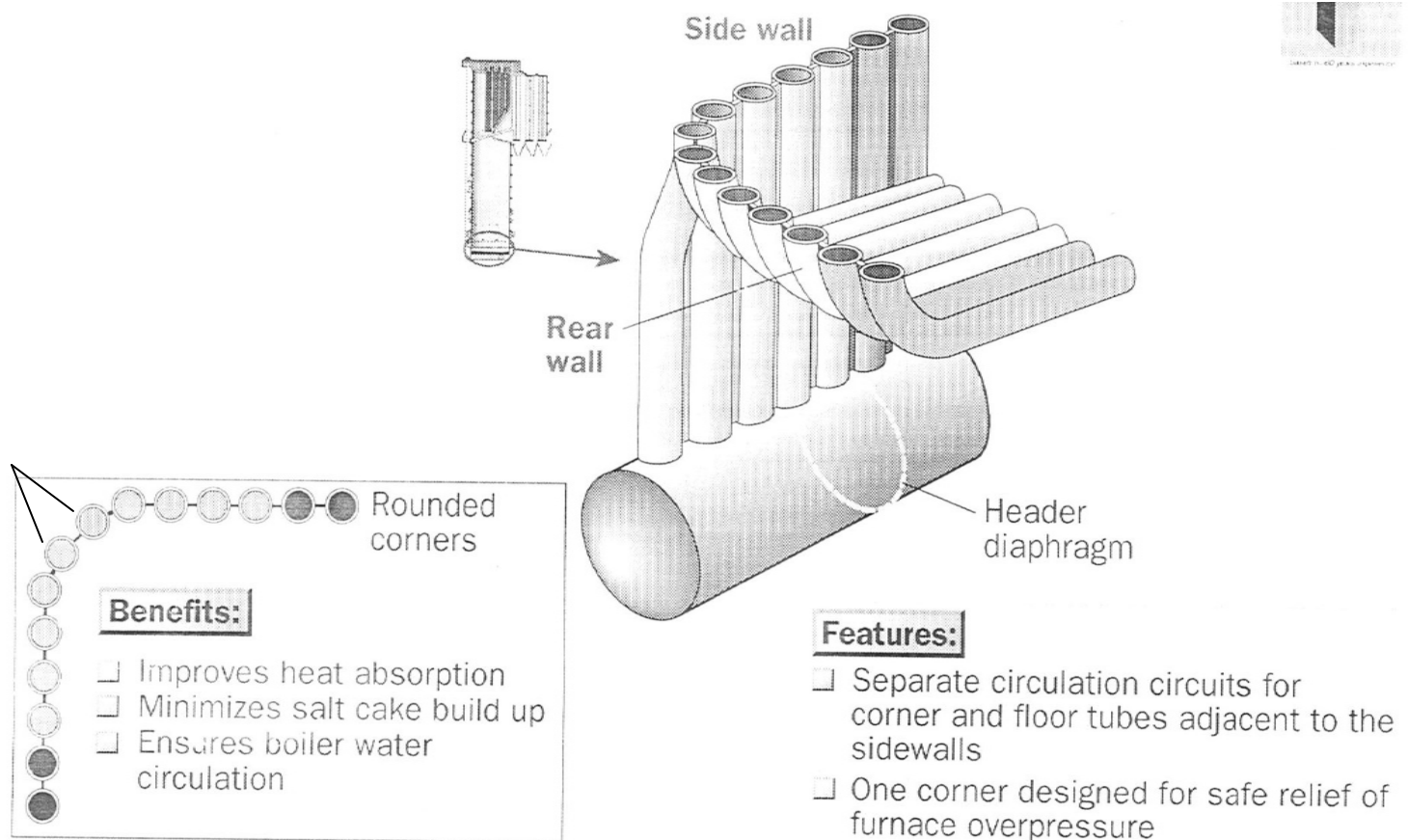
Furnace Floor Design



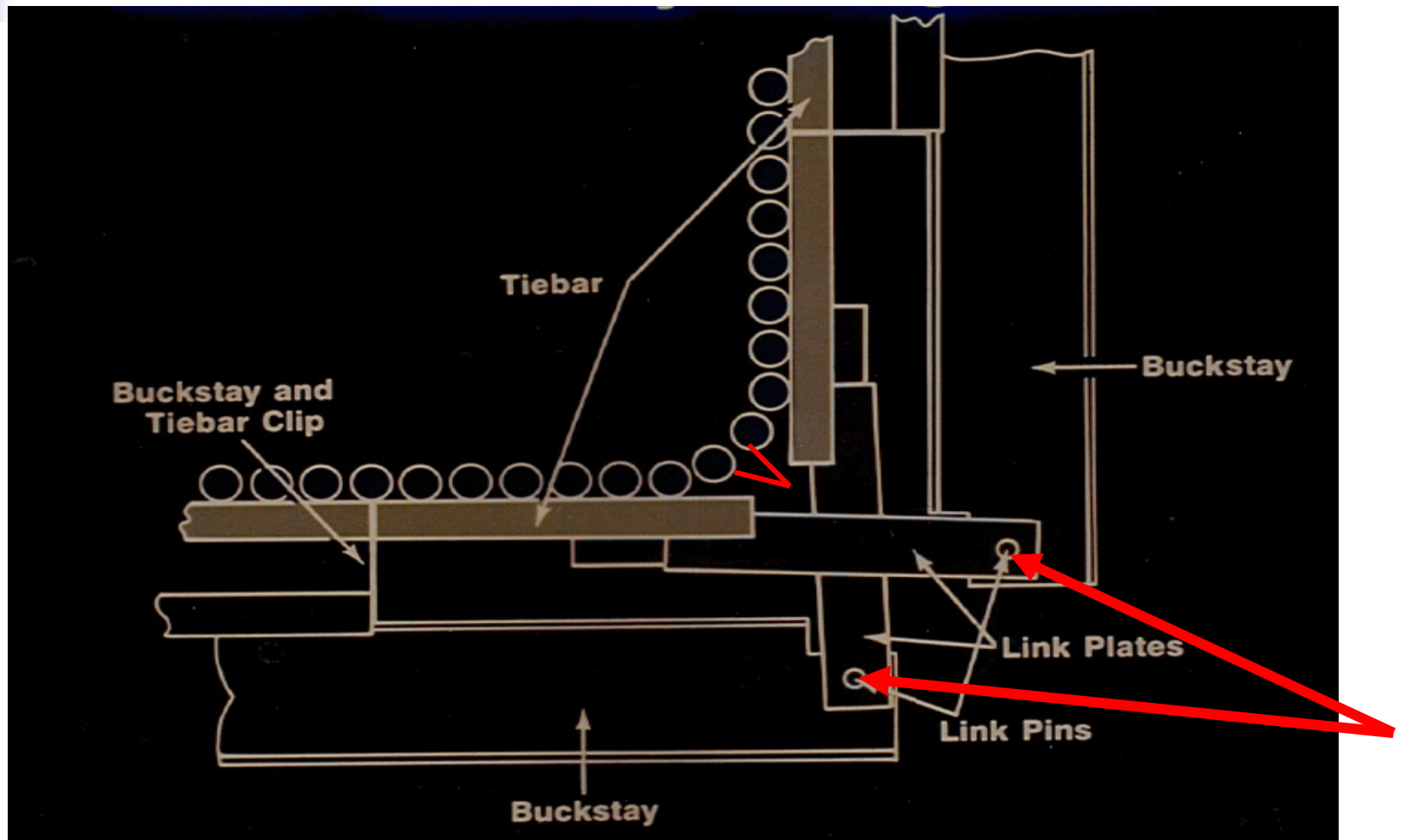
Benefits

- 2.5° slope avoids accumulation of steam bubbles inside the floor tubes
- Floor tubes always covered with frozen smelt
- Even flow of molten smelt
- Heavy duty bottom beams
- Smelt tight integrity

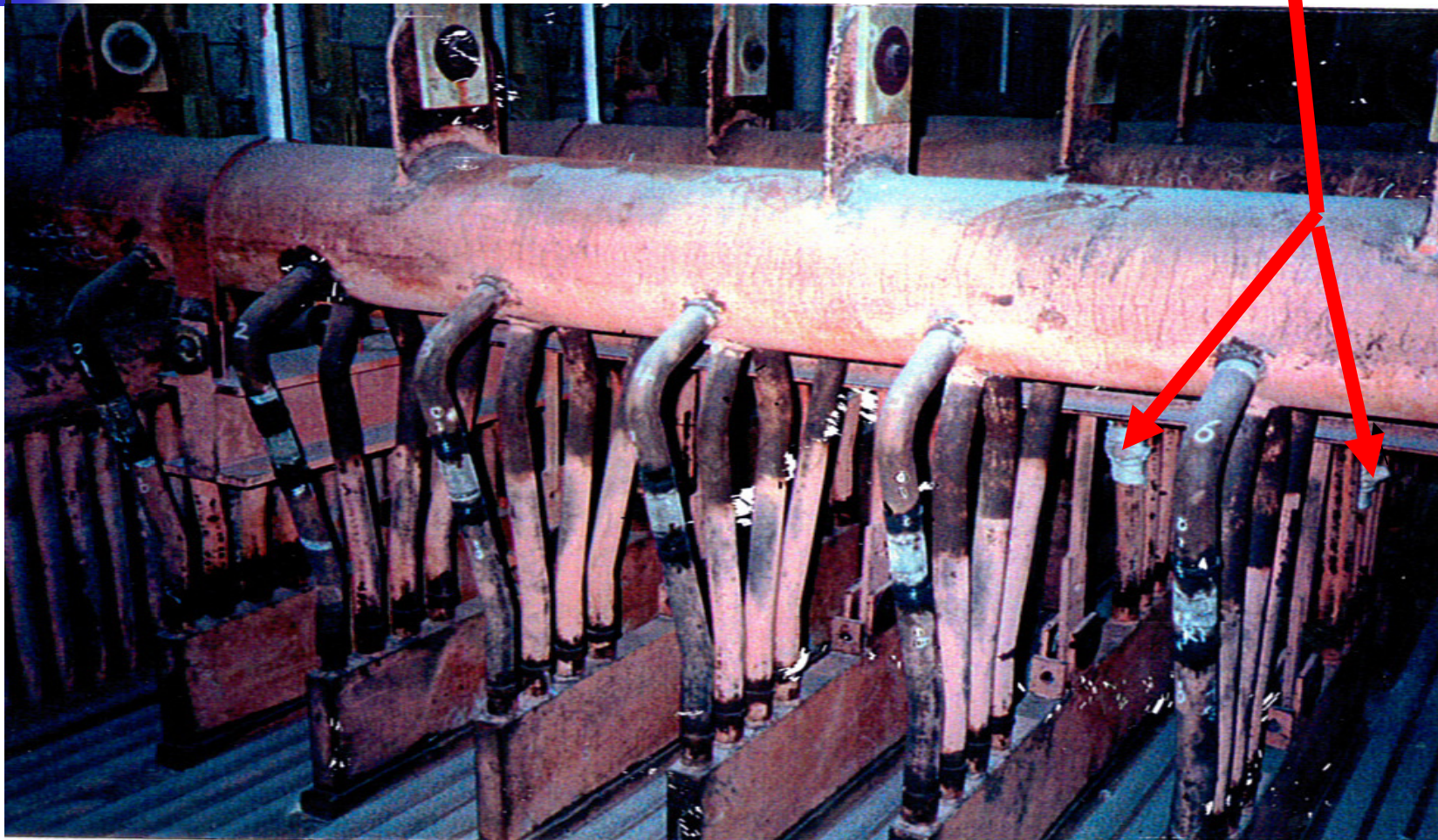
Furnace Corner Design



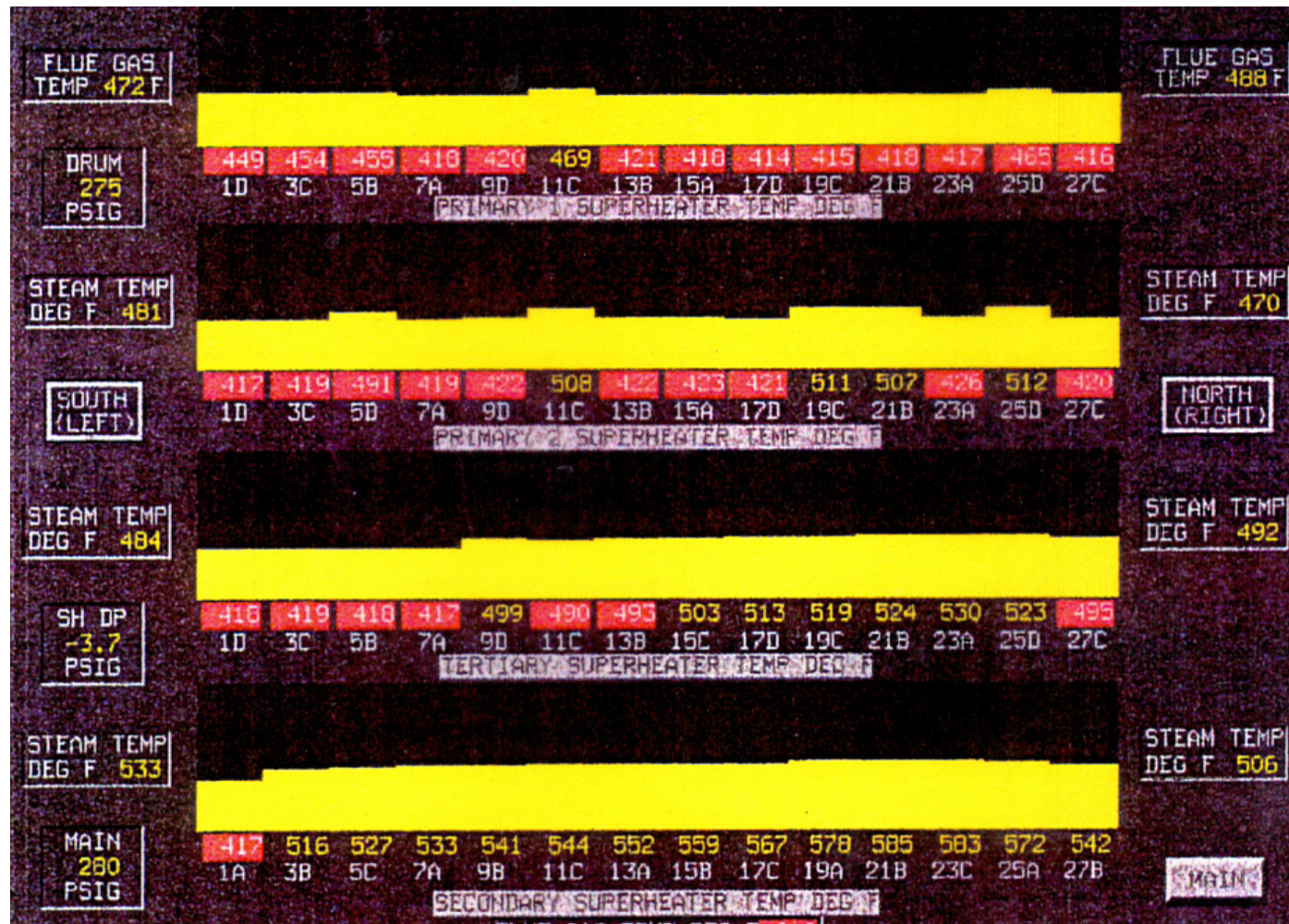
Buckstay/Explosion Corner



SH TC Location on Outlet Tubes

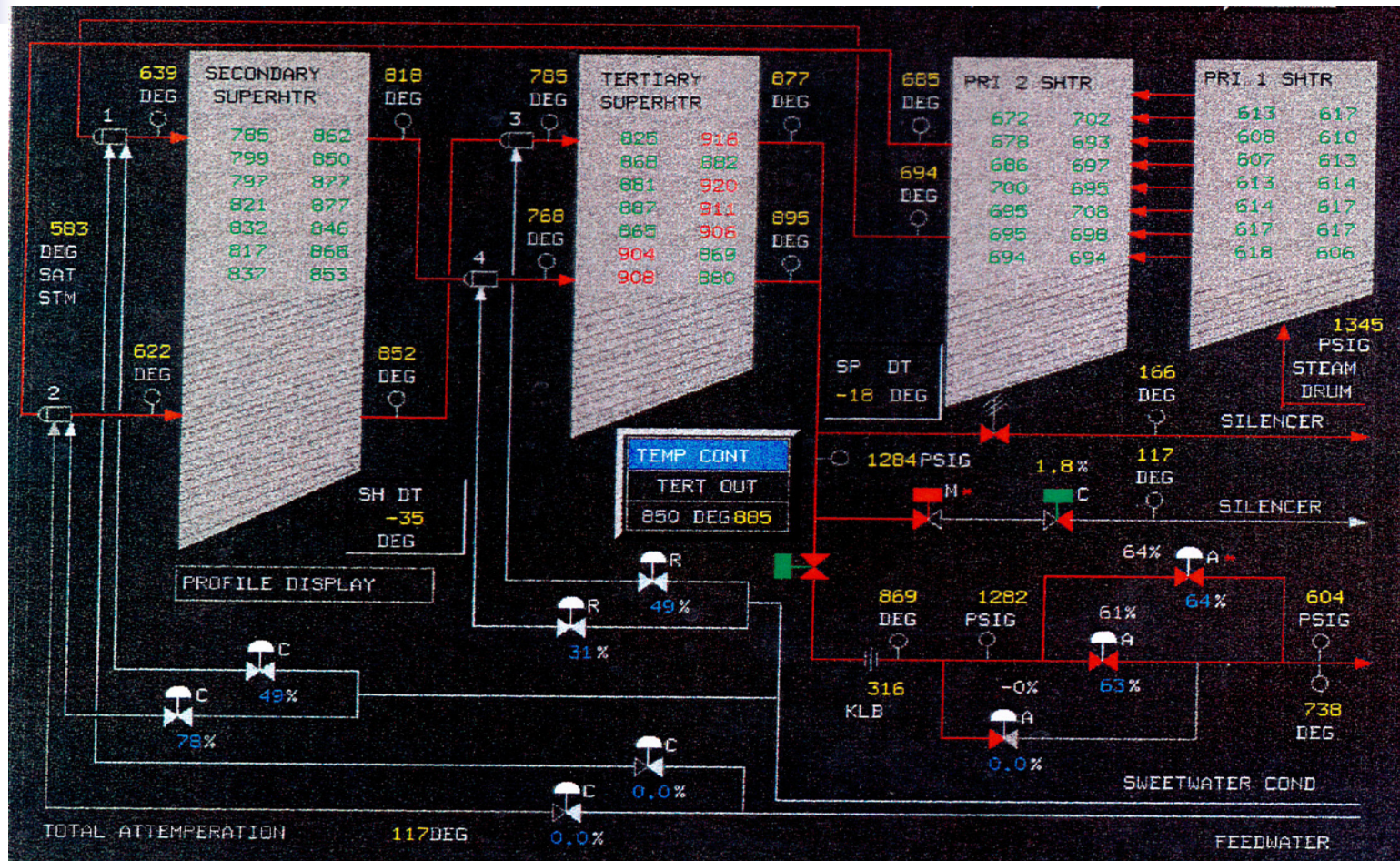


SH Thermocouples at Start-up

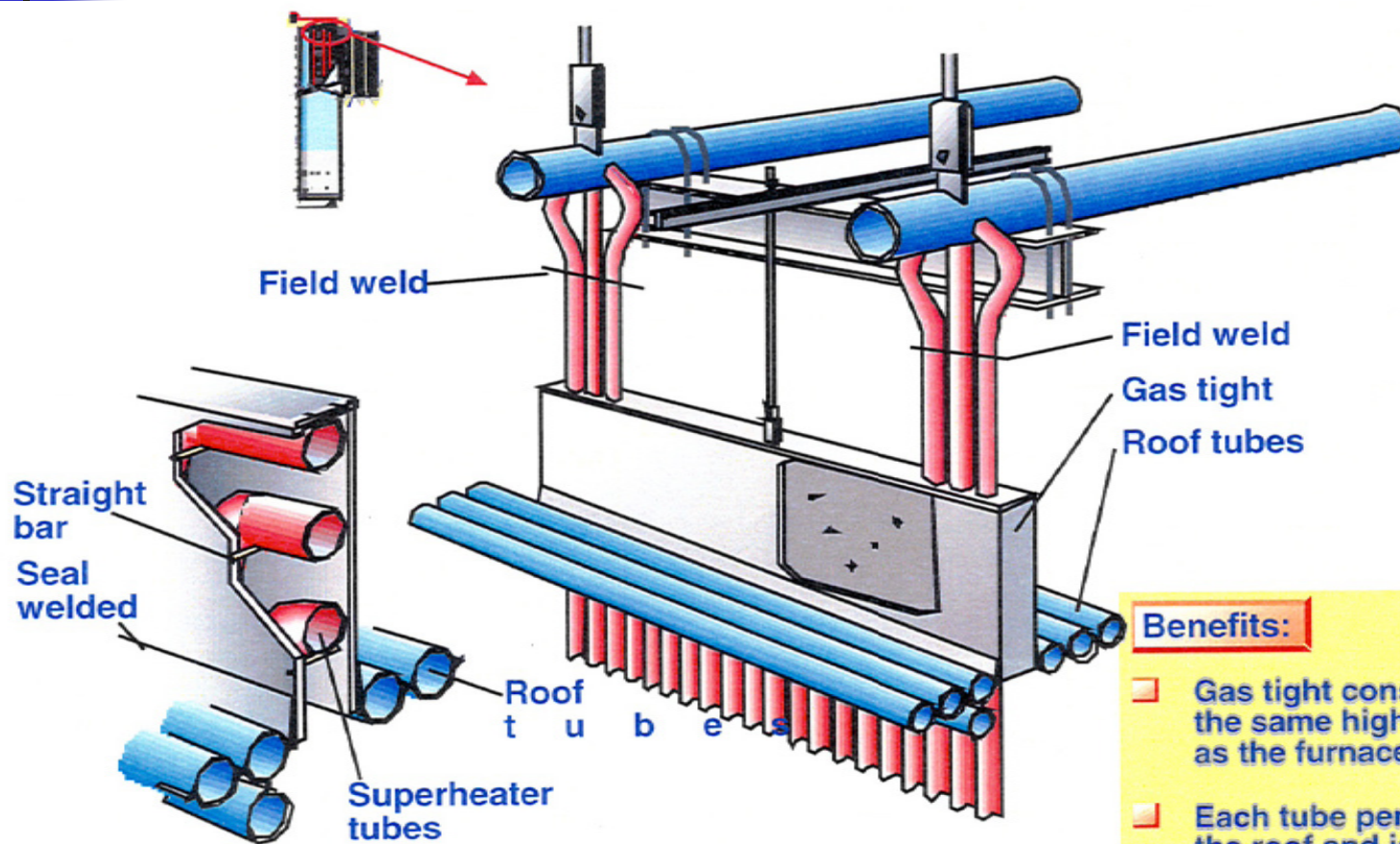


SH Thermocouple Graphic





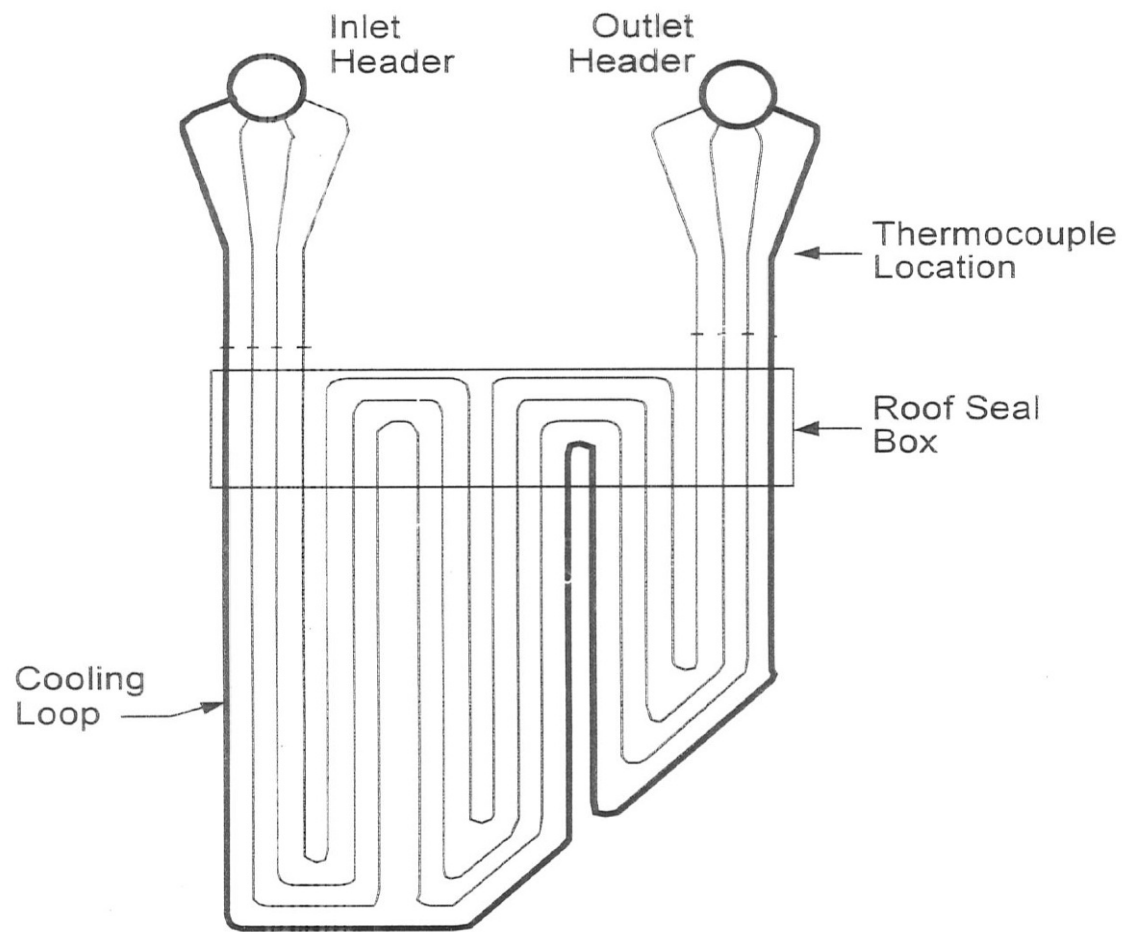
Roof & SH Support Design



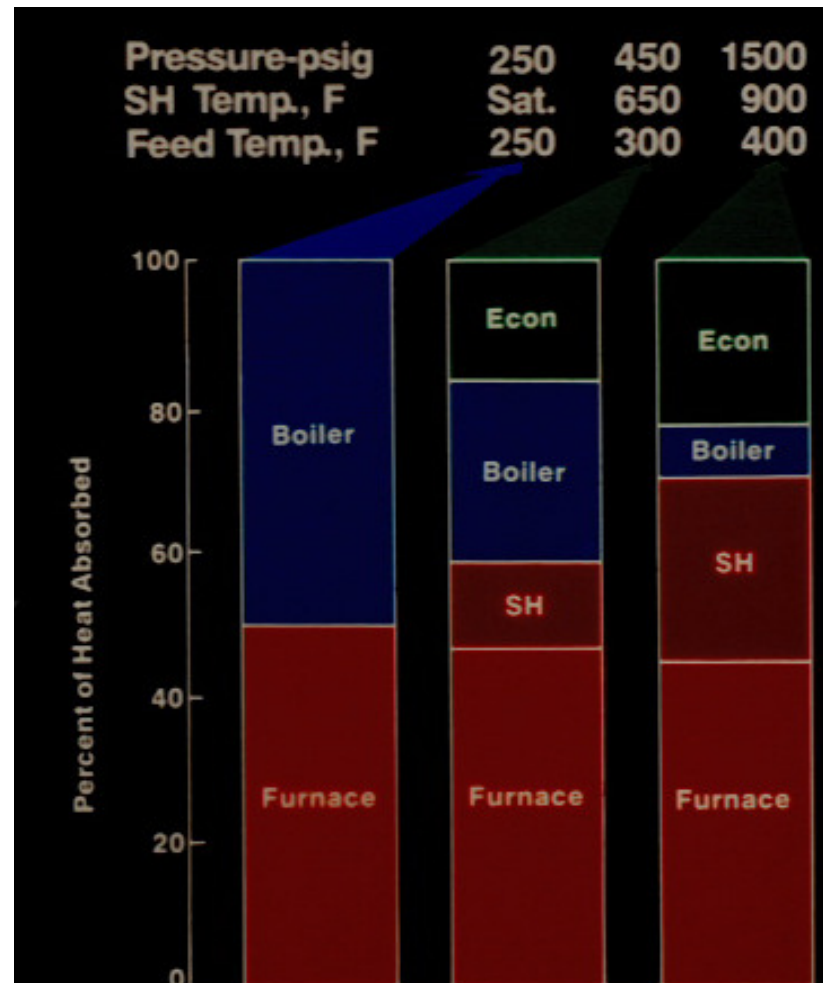
Benefits:

- ❑ Gas tight construction to the same high integrity as the furnace walls
- ❑ Each tube penetrates the roof and is individually supported

SH Cooling Loop, Sec. & Tert.

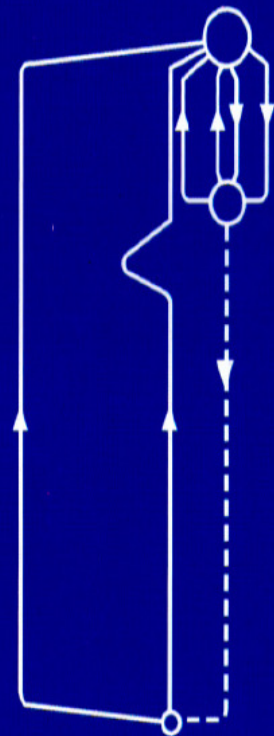


RB Heat Absorption vs. Pressure

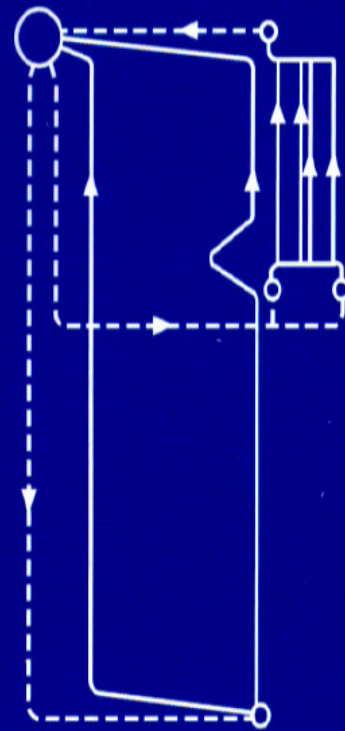


2-Drum vs. 1-Drum Circulation

Circulation Patterns Bi-Drum and Single Drum

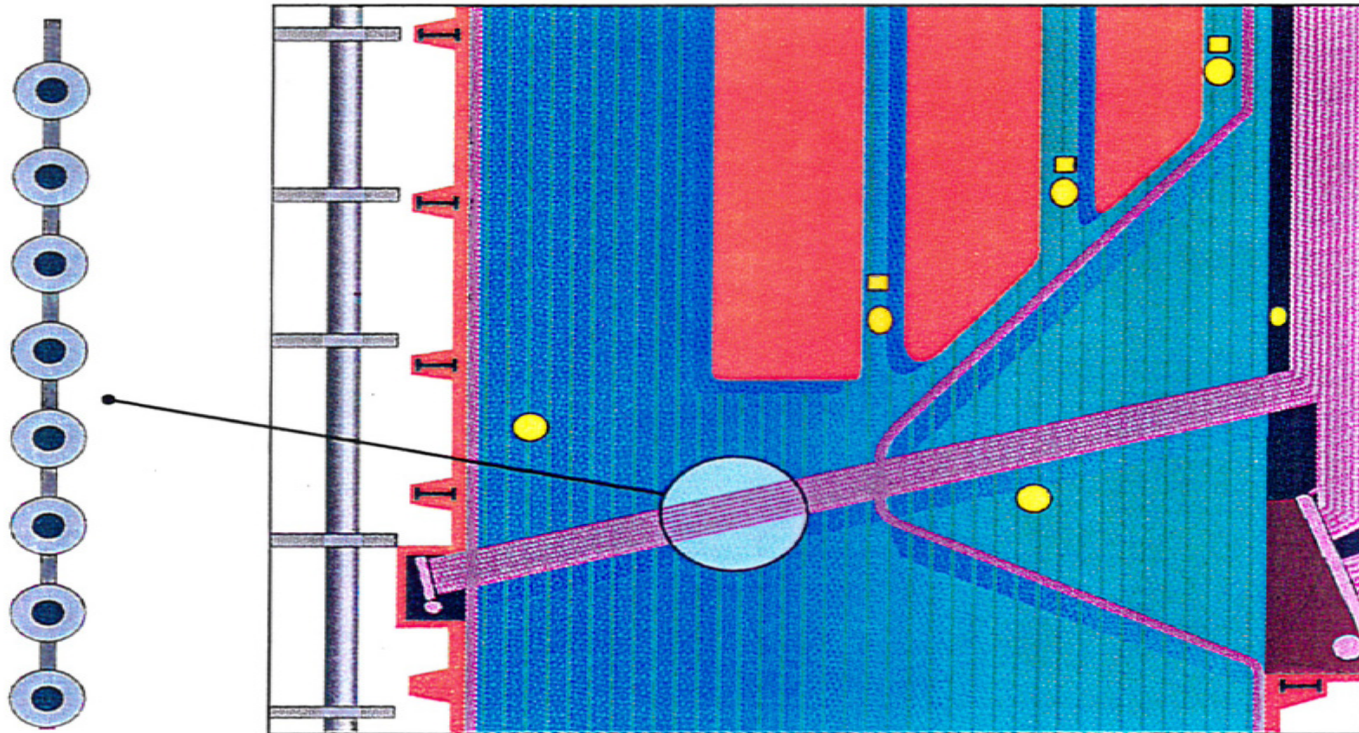


Two Drum



Single Drum

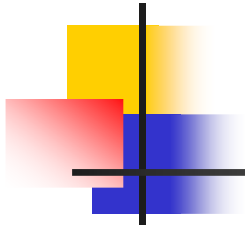
Furnace Screen Design





RB Design Improvements (continued)

- Improved ASME code welder testing/certification
- 100% radiograph of pressure part welds
- SB water washing system
- Improved NDT technology
- Vacuum spout cooling systems & dry spouts (?)
- Extra dissolving tank stack explosion relief systems
- DCS inst. & controls vs. analog; reliable CO meters; char bed CCTV cameras
- Leak detection systems
- BL concentrator technology vs. DCE



Where Inspectors Can Look

Due to extreme consequences which can result from a smelt-water reaction and corrosive nature of sulfur gasses and liquids found in recovery boilers, the following areas require attention beyond what is normally given to a power boiler;

1. Thorough NDT of the fireside pressure parts; UT, MLO, PT, Shear-Wave, CuSO_4
2. Thorough visual inspection of the pressure parts and refractory
3. Inspection of the underside of the floor for signs of smelt leaks
4. Annual replacement of the water cooled smelt spouts; inspection of the spout tube openings
5. Waterside inspection of the lower furnace, furnace screen and generating bank headers



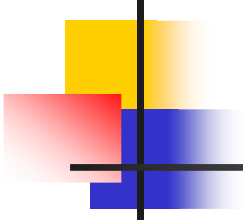
Where Inspectors Can Look (continued)

6. Regular removal of a tube sample from lower furnace high heat flux zone for FW/BW quality and DWD analysis
7. Complete functional testing of the ESP system annually
8. Functional testing of the low BL % solids divert system annually
9. Replacement of pressure parts that have <0.020 " above ASME tube MWT remaining
10. Inspect RB mid-furnace explosion corner
11. Inspect and verify functionality of scrubber by-pass (primary explosion) damper and dissolving tank secondary explosion dampers, if equipped



Summary

- RB's are better designed, operated, & inspected, but pressure part leaks still occur.
- Pressure part leaks are the largest factor in smelt-water explosions.
- There are about 100 RB leaks/yr. (N. Am.); only 1% result in an explosion ($\sim 1/\text{yr.}$).
- 2/3 of RB leaks are 1st detected at the RB (operator walkdowns).
- Half of RB explosions occur during hot restarts.
- Hot restarts (w/o 1st ensuring no leak) are driven by production pressures.
- Trained responses (ESOP's) to an emergency condition greatly reduce improper actions which can lead to RB explosions.



Questions?